Protect our protected areas!: the value of protected areas for fauna research and conservation, a case study of New South Wales

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ABSTRACT

Our aim in this study is to provide the first ever quantitative, historical and map–based information of what fauna has been studied and recorded both outside and inside the protected areas of New South Wales (NSW), which are principally National Parks and Nature Reserves. Our objective was to consider the value of National Parks and Nature Reserves for fauna research and biodiversity conservation, and gauge the extent and limits of our knowledge of the fauna of NSW. We compared the increase in the area of parks and reserves in NSW with the expansion of the fauna records in the Office of Environment and Heritage (OEH) Atlas of NSW Wildlife, and analysed the use of Scientific Licences issued by OEH for fauna research for 3.5 years to mid–2014. We found that the distribution and the number of Scientific Licences within protected areas show a heavy bias to the eastern strip of the State, with a greater clustering for the area around Sydney and the north coast, but it is evident that researchers make considerable use of protected areas.

The 6,070,769 Atlas fauna records were divided by tenure type: National Parks held 1,118,204 records (21.4 records/km^2), while Nature Reserves held 386,755 records (40.6 records/km^2). The off–park records total was 4,407,486 representing 72.6% of all records, with a density of 6.0 records per km^2. Of the grand total of all the fauna records, 7% were of threatened species. Birds and mammals comprise 81% of all fauna records in the Atlas. The greatest number of records are of birds (n = 4,913,511), followed by mammals (n = 832,361, of which 321,721, or 39%, were from WildCount).

Given the success of the growth of the number, area and distribution of parks and reserves in NSW, the idea that they can carry the heavy load of the aspiration to conserve the biodiversity of NSW now seems feasible, even desirable, especially given the increasing intensity of land use from never–ending population growth and its impacts, such as land clearing, roading, logging, water use, alien invasive species and climate change. However, this study has also revealed that we have a very poor understanding of some faunal groups, in particular invertebrates, reptiles and amphibians. Fauna accumulation curves of both records and of species match closely the growth in the area of parks and reserves since the formation of the NSW National Parks and Wildlife Service in 1967. Thus, the greater the area of parks and reserves, the greater the number of fauna records and of species. We took the historical view so that research is encouraged and the trajectory of the acquisition of new protected areas can be maintained. This study shows the ever–increasing value of protected areas to fauna conservation, and that it is vital to uphold the protected areas concept as a principal way to conserve our fauna. It should also be a guide to help recognise the importance of sustaining the effort to study our native fauna.

Key words: biodiversity conservation, Byron report (2014), camera trapping, citizen science, ecological history, environmental history, extinction, IUCN, long–term data, National Parks, Nature Reserves, Promise of Sydney, Royal National Park, scientific licences, threatened species, wildlife atlas, World Parks Congress.

DOI: https://doi.org/10.7882/AZ.2017.036

Introduction

Two events at the end of 2014 – the review of biodiversity legislation in New South Wales (NSW)[1] by Byron *et al.* (2014), and the decadal IUCN[2] World Parks Congress, held in Sydney, prompted us to focus on the tangible value of protected areas for fauna research and conservation. Specifically, we considered the deliberations of the IUCN World Parks Congress, and in particular the following paragraph from stream 1 in the *Promise of Sydney*: "Protected areas, when properly and effectively managed, are a proven effective tool for the conservation of wild fauna, flora, and fungi; the persistence of well–functioning,

1 http://www.environment.nsw.gov.au/resources/biodiversity/BiodivLawReview.pdf

2 International Union for Conservation of Nature

intact ecosystems; and are the key solution to halting biodiversity loss. In addition they are natural solutions to a range of environmental problems and social needs on land and sea, and to maintaining essential ecosystem services that underpin human welfare and livelihoods. Protected areas must be considered as mainstream contributions to true sustainable development and incorporated into national development policies. They are essential for biodiversity conservation."[3] This statement identifies the critical role of protected areas in conserving biodiversity. Similarly, the Byron *et al.* (2014) report prompted us to undertake a review of the actual value of protected areas. This report, entitled *A review of biodiversity legislation Final Report,* was influential because it provided the underpinning of new biodiversity legislation in NSW (*Biodiversity Conservation Act 2016*). In particular, we responded to the statement in Byron *et al.* (2014, p3) that "there is a lack of comprehensive information about the status of biodiversity in NSW and the extent to which conservation on public and private lands is contributing to better biodiversity outcomes." Consequently, our study set out to better appreciate the value of National Parks and Nature Reserves in NSW by undertaking a historical analysis of the conservation of fauna as the system of protected areas expanded in NSW from the first National Park in 1879. We have thus recognised the idealism of the IUCN as well as the criticism in Byron *et al.* (2014).

Changing attitudes and legal support to conserving biodiversity have been critical to fauna conservation efforts in NSW; for example, reptiles did not become protected fauna in NSW until 1974, with the passage of the NSW *National Parks and Wildlife Act 1974* (NSW), nor all frogs until 1992, following the implementation of the *Endangered Fauna (Interim Protection) Act 1991* (NSW) (Lunney 2017a). From the time of the first National Park in 1879, to an expanded system of parks and reserves that has grown rapidly from the late 1960s, setting aside areas for nature has become increasingly important. The relatively new term 'biodiversity conservation' (Adam 1998, 2013; Lunney 2017a,b) is the modern ideal, but our focus here is on the value of protected areas for fauna (birds, mammals, frogs and reptiles) because these vertebrates have been of public and legal interest for sufficient length of time to develop databases and enable analyses to be undertaken. Any historical analyses of conserving biodiversity in general richly deserve attention, but they will need to take a different path because long–term databases beyond terrestrial vertebrates do not exist within the agency responsible for conserving wildlife, the Office of Environment and Heritage NSW (OEH).

We can look at biodiversity systematically by recognising that it has many constituent parts. We are focusing on just two of these: 1. fauna, and 2. protected areas, principally National Parks and Nature Reserves. In this exercise, we link these two parts to see to what extent one contributes to the success of the other. Our approach was to look at this statement in relation to a number of vertebrate taxa, and map records to obtain a spatially explicit demonstration of the statement, as well as look at the system of National Parks and Nature Reserves to see to what extent this statement applies to our knowledge of the protected areas of NSW.

Our aim in this study is to provide the first ever quantitative, historical and map–based information of what fauna[4] has been studied and recorded both outside and inside the protected areas of NSW, which are principally the National Parks and Nature Reserves. We utilised the information held by the Office of Environment and Heritage NSW (OEH)[5] to compare the increase in the area of the National Parks and Nature Reserves in NSW with the expansion of the fauna records in the OEH Atlas of NSW Wildlife and Scientific Licences issued by OEH for fauna research. To extend our knowledge, we also compared the distribution of fauna records in National Parks and Nature Reserves with off park records in NSW, and the use by research zoologists of National Parks and Nature Reserves with land other than in parks and reserves. Our objective was to consider the value, or rather the rate of increase in the value, of National Parks and Nature Reserves for fauna research and biodiversity conservation, and gauge the extent and limits of our knowledge of the fauna of NSW. We are fortunate that we have the advantage of knowing how to access records within OEH that are not readily visible or accessible. The files are not inaccessible, they are not hidden, but finding, assembling and comparing large and diverse data sets can be too tedious, difficult, or vague without 'inside' knowledge.

In order to evaluate the role of protected areas in fauna conservation, we present data, maps and our interpretation of the information held in the NSW Wildlife Atlas (which lies within Bionet) and we present summaries of the following information on:

- the total number of fauna records held, the number of records per fauna group, the number of entities identified, including feral and native;
- the number and density of records in conservation reserves, off park, and in wilderness areas;
- patterns of feral, native and threatened species in NSW both within and beyond parks and reserves;

3 http://worldparkscongress.org/downloads/approaches/Stream1.pdf, last accessed 14 June 2015

4 Fauna was defined by the *Fauna Protection Act 1948* (NSW) as comprising two classes of native vertebrates: birds and mammals. The *National Parks and Wildlife Act 1974* (NSW) added reptiles in 1974, and 12 species of frogs in amendments in 1983, the *Endangered Fauna (Interim Protection) Act 1991* (NSW) added all species of frogs as protected fauna, and the *Threatened Species Conservation Act 1995* (NSW) expanded fauna to include threatened invertebrates. We are using the expanded definition in this paper.

5 OEH is a NSW government agency that protects and conserves the natural environment, including the establishment and management of National Parks and Nature Reserves, and conserving wildlife.

- those species that are reported most frequently and discuss why and how this may bias the interpretation of results;

- patterns of reporting species in protected areas (subdivided into National Parks, Nature Reserves, State Conservation Areas and other protected areas) across the state of NSW and identify areas of highest research use;

- patterns across bioregions and how this has changed over time to identify areas where information is limited;

- whether the size or type of protected area (e.g. National Park or Nature Reserve) has any influence on research intensity;

- important data contributors and demonstrate how research intensity varies over time and across the landscape within specific programs;

- the pattern of threatened species (Critically Endangered, Endangered and Vulnerable), protected species (native species that are not threatened) and exotic species inside parks and reserves and outside of the protected area system; and

- changes in size of the protected area system in NSW and compare this change in size to the number of records collected and the number of species.

Linking our knowledge of fauna with the growth in protected areas

Knowledge of the species in each protected area in NSW, along with the number of records of species, has grown rapidly in the last four decades, but the link between the accumulation of these records and the growth and location of protected areas does not appear to be at the forefront of strategic thinking. That we have produced the first graphs of these rates of growth implies that others are not looking at a time scale of conserving biodiversity. We agree that it is hard to do so, the datasets are difficult to locate and interpret, so it is much easier to look across the landscape at one point in time and not at the growth in both new area acquisition and new knowledge of species. However, only through an extended time scale can we see the true extent, or at least the rate of growth, of the value of protected areas for fauna conservation.

Spatial analyses, not possible until relatively recently, reveal limitations in protected areas for conserving species. Imagine if these analyses were to be repeated, retrospectively, for each year for the last half century, what picture would emerge? We conjecture that it would tell of a growth in the success of conserving species in protected areas. We also conjecture that this success would not be a neat linear relationship, partly because of the way that new parks and reserves were located and partly because of our lack of basic knowledge of species' distributions. We notice, for example, the use of the Commonwealth's list of threatened species in various studies (see Lunney 2017b for the details), but we contend that this dataset has definite limits.

By the time a species appears on the Commonwealth list it has been thoroughly reviewed and considerable data are available. If we switch our attention to the non–threatened species, which are a State rather than Commonwealth responsibility, then the datasets are limited and thus potentially misleading. Further, the emphasis in the last quarter century on threatened species in NSW at the expense of non–threatened species (some of which are defined as data deficient) has swayed the conservation agenda (see Lunney 2017b for a detailed historical account of the hegemony of threatened species), and non–threatened species have become the neglected species. Similarly, some species referred to by Fleming and Bateman (2016) as 'the good the bad and the ugly' attract more or less research than others. Analyses that draw only from Commonwealth datasets of threatened species potentially produce a biased picture of the status of all species, even of vertebrates. The most obvious conclusion is to increase the effort to determine the distribution and dynamics of all our fauna, not just today's list of threatened species, and that includes in both protected and non–protected areas (Lunney 2017a,b,c). The case for stepping up our investment in ecological research into conserving biodiversity grows stronger as the environmental crisis becomes more apparent each year, and the call to address the matter becomes more determined.

The importance of data, or how the Byron report pushed us to write this paper

In a history of Royal National Park, Australia's first National Park dedicated in 1879, Lunney (2014) found that the development of the reserve system was initially slow, and fauna conservation was not the motivation for park establishment. Lunney (2017a) also makes the point that until recently the emphasis in the management of National Parks was on recreation, with the aspiration of conserving a nation's fauna being a much more recent enterprise. By the 1950s, this had begun to change in NSW into a modern outlook with the dedication of Nature Reserves under the *Fauna Protection Act 1948* (NSW), with Nadgee Nature Reserve being an exemplar of the modern vision of combining protecting natural areas, conserving fauna and encouraging research (Lunney *et al.* 2013).

Within the details of their review, Byron *et al.* (2014, p 68) stated that, "information is a cornerstone for effective decision making". We agree and we have written this paper to make public available information that is not readily accessible, or at least its presence and value not explored. In their chapter, 'Knowledge, information and science', Byron *et al.* (2014, p 68–76) outlined the central requirements for data and information to inform issues ranging from the assessment of extinction risk to reporting actions to conserve biodiversity. However, from our reading

of the text, they did not relate this to the specifics of the State's fauna, nor the distribution of protected areas, nor did they examine the two primary sources for such fauna information, namely the Office of Environment and Heritage NSW Atlas of NSW Wildlife, a scheme for recording fauna records, and the Scientific Licences issued by the OEH, nor did they look at the spatially explicit databases for National Parks and Nature Reserves in NSW. Regardless of limitations of the available datasets, there is an obligation to be more inclusive of the range of views than the two quotations in Byron *et al.* (2014, p 68) – one from the Environment Liaison Office, the other from the NSW Minerals Council[6]. These quotes do little more than assert serious deficiencies in data and the state of mapping in NSW. There were no countervailing quotes as to the value of what is known and available. This is misleading reporting. In this paper we give a practical assessment of the value of the two formal databases held by OEH.

We know that some, or even much, of this information has, in the past, been difficult to access and so we recognised the duty to make this information more public. We also examined the value of protected areas for scientists studying fauna based on the analysis of two separate record systems: the Scientific Licences[7] issued for studying fauna, and the fauna records in the Atlas[8]. These are steps towards a broader aim of assessing the value of protected areas for fauna conservation in NSW in order to achieve the long–term objective to conserve all our fauna in perpetuity, irrespective of land tenure.

As zoologists, we agree with the aim of the Byron review that the legislation currently under review has an important but excessively narrow focus on identifying threatened species, populations, ecological communities and key threatening processes and that it does not adequately provide for broader monitoring, evaluation and reporting that includes all the State's fauna (Lunney 2017b,c). Byron *et al*. (2014) propose that for the effective conservation of biodiversity, data and information are needed to inform: "1. extinction risk assessment for species and ecological communities, 2. threat and risk assessment to prioritise actions to ameliorate threats across the landscape, 3. tracking biodiversity status across NSW, 4. understanding the values of biodiversity to the community, 5. predicting and modelling the impacts of different actions, and 6. reporting on the outcomes of actions to conserve biodiversity." As Byron *et al*. (2014, p 68–69) point out, "these elements are essential for an adaptive management approach", which they describe as one that "systematically integrates results of management interventions to iteratively improve management". To help meet that challenge, we examined two major OEH databases that can supply data and information to assist in achieving these six elements in an adaptive management approach.

We also know that the Atlas scheme can be misused. An example of misuse is to consider that consulting the Atlas is all an assessor needs to do to determine the presence of a species in a proposed development site; or that a corporate entity can attempt a monitoring program just on Atlas records. To take these approaches would compromise achieving any of the goals in the Byron review. Potentially, however, one can draw on the Atlas of NSW Wildlife to examine the spatially explicit records for their distribution within National Parks and Nature Reserves, *i.e.* protected areas, or other land tenures, as well as any proposed development site.

We recognise that the Atlas is an opportunistic repository of available information (*e.g.* faunal records) from a variety of sources. It is not the result of intensive, repeated, state–wide, systematic faunal surveys. Even major initiatives for fauna survey are limited, as they are focused on some faunal species or some parts of the State. This does not necessarily represent a limitation on any survey, nor the Atlas, but rather it leaves a potential gap between the intent of any survey and the way the results may later be utilised. If we are ever to achieve the ideals expressed in Byron *et al.* (2014), then it is important that we evaluate the current data schemes and identify their strengths and limitations.

Thus, one aspect of this paper is to present the strengths and limitations of our knowledge of our fauna, and our faunal knowledge in protected areas. We acknowledge that different interrogations of the Atlas database may come to separate conclusions, ranging from necessary or unacceptable constraints on major developments to the selection of new protected areas. However, we looked more broadly at the distribution of our faunal knowledge, particularly in relation to protected areas.

IUCN World Parks Congress[9], Sydney 2014

Arising from IUCN World Parks Congress is a statement relevant to this paper[10]. Paragraph 10 of the 13 paragraphs in stream 1 is pertinent to our study of Atlas and licence records for fauna: "There remains

6 Under the heading, 'Knowledge, information and science' (Byron *et al.* 2014 p 68), the two following quotes are prominent in the margin of the page: "'Data currently collected on biodiversity in NSW is vital and should be maintained; however the lack of detailed data on the value of protecting biodiversity in NSW is a serious deficiency'. Environment Liaison Office." And "'The state of NSW mapping and data with regard to biodiversity is inadequate. This is the cause of uncertainty for developers and farmers, considerable delay in assessment and undermines the aims of the Offsets Policy to streamline the offsetting process and reduce negotiation'. NSW Minerals Council."

7 A Scientific Licence is required to study fauna anywhere in NSW, and for any research in National Parks and Nature Reserves, or other areas of the National Parks and Wildlife Service estate.

8 NSW Atlas is the website for the Atlas of NSW Wildlife. It is a whole–of–government system for flora and fauna sightings information. Atlas is a portal for accessing government–held information about plants and animals in NSW. It is supported by several NSW government agencies.

9 Dan Lunney is a member of the IUCN World Commission of Protected Areas.

10 http://worldparkscongress.org/downloads/approaches/Stream1.pdf, last accessed 14 June 2015

insufficient attention to monitoring the biodiversity outcomes of protected areas, in terms of ecosystem extent and condition, and species extinction risk and population trends, to allow evidence–based management and provide incentives for success". However, the Congress also noted, "an explosion of innovative monitoring technologies, tools, and activities that have generated huge volumes of new biodiversity data, but now require effective data management systems to ensure that these new data can inform immediate responses." Paragraph 10 also stated, "Protected area managers, individual researchers and governments must be far more open and proactive about data sharing and keeping high quality records. Regional protected areas' 'human' networks can play an important role in data sharing as well as in capacity building." Thus, in 'Recommendations for change', point 19 stated, "Governments and all sectors must adopt greater consistency in the collection, evaluation and reporting of biodiversity data within each country and globally, inside and outside protected areas, and make these data discoverable, available and accessible to support evidenced based decision making".

It is this entreaty in the *Promise of Sydney* to evaluate and share information that helped propel our study. Under "key partnerships" needed in the *Promise of Sydney*, we note the following plea: "Scientists – Focus research on understanding the contribution that protected areas can make to biodiversity conservation." We thus have a contemporary appeal that underpins the aim of our paper as scientists working with wildlife and in protected areas in NSW. This paper plots the increase in value of protected areas in NSW for both fauna conservation and for scientific research. In parallel to examining the current records for NSW, the trends in the global picture and their application to Australia are examined by Lunney (2017a). However, the point reinforced here by the *Promise of Sydney* on the importance of protected areas for conserving biodiversity has been part of our working lives. What we do recognise is that while these ideas were gaining ground post World War II, their acceptance has been hard won by many skilled and articulate thinkers and the rate of growth of both protected areas and of knowledge of our wildlife has been modest until the last few decades.

Methods

Scientific Licences

In 1974, a licensing system was introduced by the National Parks and Wildlife Service NSW (NPWS) for researchers who wished to undertake research in protected areas as well as for anyone studying fauna anywhere in NSW (see Figure 1 for study area). One of us (Lunney) reviewed and issued Scientific Licences for 10 years, so their value for both science and wildlife management, including law enforcement, is appreciated by this paper's authors. However, it is only recently that this system has been computerised and this now allows us to readily answer such questions as how many licences are there, for what faunal groups, and in what locations in the State? Licences give approval to undertake research on the fauna, so they are statements of intent for the faunal groups and for location. The Atlas (described below) holds the data obtained under a Scientific Licence, as well as other records such as bird watching (and bird watchers are great contributors of fauna records), and these records are then available for wider use.

In this study, Scientific Licences were searched for the 3.5 years from 2011 to mid–2014. This corresponds to the period from when electronic licences started to the lead up to the 2014 Royal Zoological Society of NSW (RZS) forum on fauna and protected areas, where we presented these data. We searched the licences by licence number, location, fauna or faunal groups, and the description of the activities to help us to determine location and/or faunal group. We did not have access to the names of the licence holders. We analysed the data by land use, principally on or off protected areas, by fauna group, and by location. Within the protected areas, we ranked the top 10 National Parks and Nature Reserves for use, based on the number of licences issued and calculated the density of licences (based on reserve size) in each reserve. We mapped the location of the licences issued for each faunal class within the protected area system, and we also recorded the total of all vertebrates, as well as invertebrates and marine animals (marine mammals and reptiles).

The Atlas of NSW Wildlife

The Atlas of NSW Wildlife needs detailed explanation because of its public and scientific importance. It is the OEH's database of flora and fauna records[11]. As the website explains, it contains records of plants, mammals, birds, reptiles, amphibians, some fungi, some invertebrates (such as insects and snails listed under the *Threatened Species Conservation Act 1995*) and some fish. It has existed in various formats since 1980. As of August 2012 (as stated on the website on 14 June 2015), the Atlas contained over 6.4 million records authorised for distribution by the OEH, plus a further 3.7 million records supplied by other custodians for internal OEH's use only. It is managed by staff in OEH's BioNet–Atlas Team.

The Atlas is a recent innovation, and its origins are clear from a paper by Murray Ellis (1992). In his Table 1, the 'Number of fauna records by class as of August 1992', the information is modest indeed: Frogs 1606; Reptiles 5,765; Birds 87,710; and Mammals 18,900; giving at total of 113,981 records. While Ellis entitled his paper, 'Revision of the Atlas of New South Wales Wildlife', he also played a major part in its establishment. Generously, and correctly, he acknowledges the work of a former NPWS colleague: "In 1981 Bruce Gall, with the NSW

11 http://www.environment.nsw.gov.au/wildlifeatlas/about.htm, last accessed 14 June 2015

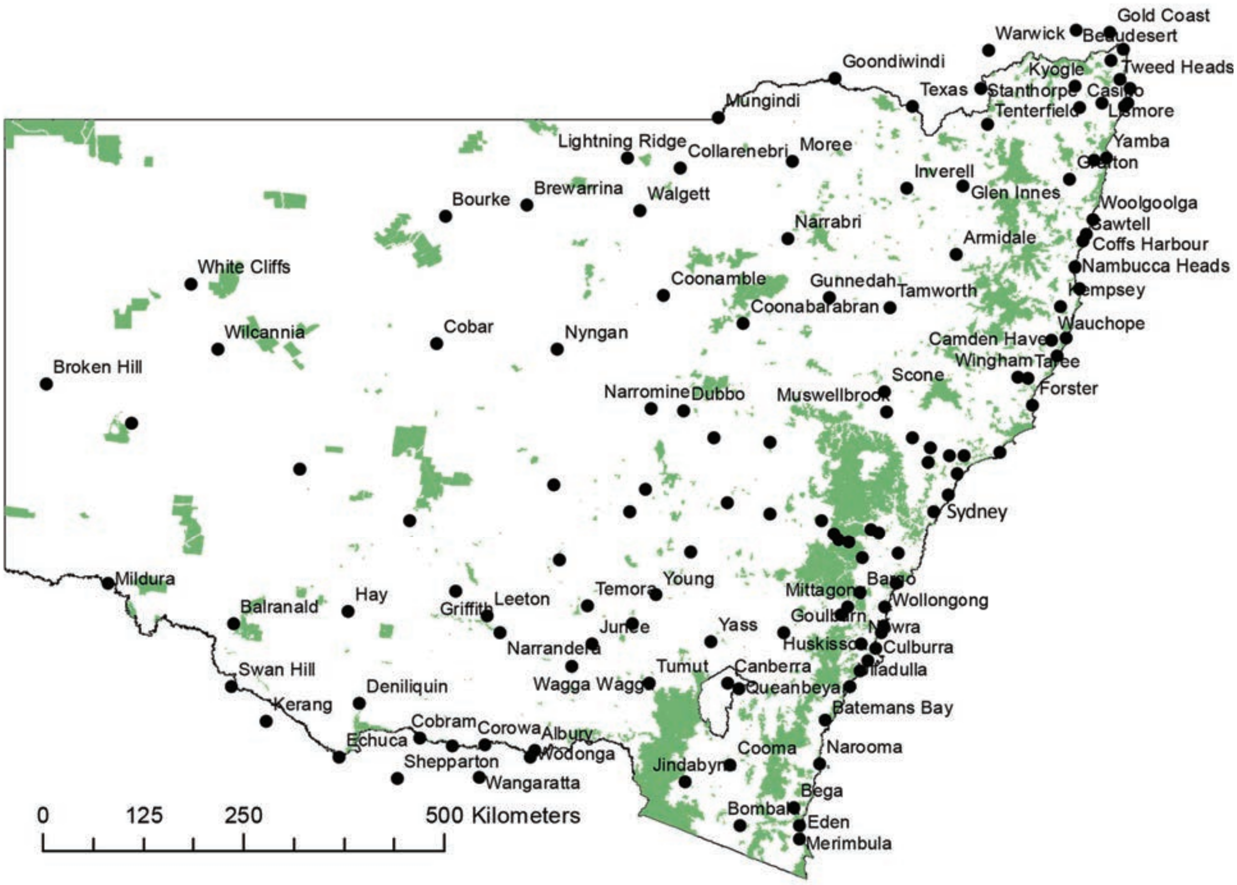

Figure 1. Study area (NSW) showing conservation reserves (green) and major towns as of 4 November 2014. NSW is bound by land to the north (Queensland), south (Victoria) and west (South Australia), with the Tasman Sea forming the eastern boundary.

National Parks and Wildlife Service (NPWS), started an "Inventory of New South Wales Wildlife" which soon became known as Wildata (Gall and Christian 1984). It was a computerised system to record sightings of vertebrate fauna, mainly from NPWS staff. The basis of collecting the records was that sufficient occurrence records would eventually elucidate the distribution (and changes to it) of the various species. It was also envisaged that it would allow rapid retrieval of information that had already been collected." One of us (Lunney) remembers Bruce Gall waxing lyrical about the atlas scheme he had just seen in the UK, where he had been on holidays in the late 1970s. It did take some time to set up, and at the time Murray Ellis was working on the project computers were a novel addition to the NPWS's infrastructure, and individual staff members did not have computers on their desks. Ellis' (1992) concluding statement in his paper remains true today, and we are working with that outlook: "The value of the atlas will depend on the quality and extent of the data held within it. A wide spread of records across time and space is needed if we are to understand the needs of, and threats to, various species. The higher the accuracy of the geographic location of the record the more use it will be in modelling species distributions at the local level. However, for rare and poorly known species even imprecise records can be invaluable in furthering our knowledge. Similarly, historical records are very important if we are to determine the past distribution of each species and hence assess if its range is contracting or not." When we look at identified shortfalls in the current scheme we may well agree, but we are also well aware of the rate of increase in its value in a quarter of a century. Thus we need to recognise that its value is growing, so we not only support the scheme, but suggest that scientists could be encouraged to make more use of it for analyses, and publish their findings. Public reviews depend upon such analytical studies, and the grey literature, including internal reports, are not nearly good enough, given the increased importance placed on acquiring and disseminating fauna distribution data, and of important reviews such as the Byron *et al.* (2014) report.

The flora and fauna records in the Atlas, as listed on the website, come from various sources, including: survey data held in the Atlas' inbuilt systematic survey modules (fauna survey and VIS Flora survey), Office of Environment and Heritage including data from the Royal Botanic Gardens herbarium database and from National Parks and Wildlife staff, data submitted by ecological consultants, research scientists and others (as part of the Scientific Licence procedure), data provided by other agencies, such as Forests NSW, the Australian Museum, Birdlife Australia and the Australian Bird and Bat Banding Scheme, historical reports, and the general public.

In outlining the type of information that is contained in the Atlas, the website explains that: "Data in the Atlas, whilst extensive, is nevertheless 'patchy'. The Atlas covers all areas of NSW and also includes some records from neighbouring states, but will not provide information on the full distribution of a species. The Atlas is not a comprehensive inventory of all species, nor of all locations of species in NSW. Except in areas where detailed survey information has been incorporated into the database, the search results for a particular area are based on a mix of reported sightings. For example, sightings often follow patterns of human movement, such as along roads. It is also important to realise that the number of recorded sightings for a species does not necessarily correspond in any way to the actual abundance of that species in NSW. Contributors often focus their efforts on recording threatened and endangered species, with the result that rare species may have more recorded sightings in the Atlas than common species. A common species in an area may not be recorded in the Atlas, because no–one has thought to report its occurrence."

We regard these official cautions and caveats as critical to understanding both the strengths and limitations of the Atlas. We also note such phrases as: "The Atlas is not a comprehensive inventory of all species, nor of all locations of species in NSW." We looked at this statement in relation to a number of taxa, using map records to obtain a spatially explicit demonstration of the statement, as well as looking at the system of National Parks and Nature Reserves to see to what extent this statement applies to our knowledge of the protected areas of NSW. The Atlas itself is a passive database, it records but does not initiate surveys, studies or data collection. One of the consequences of passive recording, and the initiation of very few state–wide, systematic surveys, is that biases in location can readily occur. This paper gives graphic illustrations of these locational and species biases. It is essential to understand them when appraising the value of protected areas, or any other exercise, such as the impact of climate change on species' distributions. Data quality is one issue we have not specifically analysed in this review; however, we note that any atlas contains errors resulting from misidentifications, inaccurate geographic locations and other faulty inputs, and we encourage users to assess data quality alongside the biases we uncover and ensure the information is fit for purpose before interpreting the data.

WildCount

The Atlas also contains wildlife records from WildCount, an OEH initiative for monitoring fauna, which is explained on the OEH website[12] as follows: "It is easy to believe that common native animals like kangaroos, possums, lyrebirds and wombats will always be around. Is it possible, that, despite being relatively common, they are in decline? WildCount aims to answer this question. WildCount is a 10–year fauna monitoring program that uses motion–sensitive digital cameras in 208 sites across 146 parks and reserves in eastern NSW. WildCount looks at trends in occurrence of animals at these sites, to understand if animals are in decline, increasing or stable. Based on current data, WildCount can confidently detect changes in occurrence of 12 species over ten years. As we get more data over time, the list below is expected to grow." WildCount lists its current species as "Swamp wallaby, Red fox, Short–eared brushtail possum, Common brushtail possum, Red–necked wallaby, Red–necked pademelon, Superb lyrebird, Eastern grey kangaroo, White–winged chough, Common wombat, Long–nosed bandicoot, Australian brush–turkey." The websites informs us that, "WildCount will be able to detect if there is a change in occurrence that meets the criteria for listing species under the IUCN Red List. The power to detect such change means OEH can examine other broad trends such as increase in pest species. Understanding these changes in native and pest species will assist in the management of parks and reserves. WildCount focuses on monitoring typically common and widespread species."

12http://www.environment.nsw.gov.au/animals/wildcount.htm, last accessed 14 June 2015.

What both the Atlas and WildCount websites make clear is that the input of data is selective. For example, data in Lunney *et al.* (2009) for their 2006 state–wide wildlife survey were limited to 10 iconic species, because these were the species that were considered to be unambiguously recognisable in a citizen science survey. Similarly, WildCount counts only those animal species that are picked up by cameras, and can be identified by later analysis of the photos. The examples provided by the WildCount website show the types of animals that can be monitored. It does not, for example, include the platypus *Ornithorhynchus anatinus*. Thus, if one understands the nature of the data being recorded in the Atlas, then the biases are understandable and adjustments can be made when undertaking particular analyses. However, not every user will be aware of the sources of the data and design of the survey and therefore the potential impact of the biases that exist in the record system. On this note Szabo *et al.* (2012) offer the following caution which is applicable to all datasets (not just citizen science): "Using volunteer–collected data can be misleading if people who interpret them and use them for research or decision–making do not understand or consider the limitations and biases inherent in these datasets."

Processing Atlas records

We examined fauna records in the Atlas in order to document trends in reporting over time and between faunal groups. Records were downloaded from the Atlas (14 August 2015) for the following animal categories: mammals, birds, reptiles, amphibians and invertebrates. Nomenclature used throughout this paper is as downloaded from the Atlas, we have not changed the names of species and, as a result, the names used herein may differ from what is currently becoming accepted (e.g. Jackson and Groves 2015 refer to the red–necked wallaby as *Notamacropus rufogriseus*, whereas the Atlas at

the time of download used *Macropus rufogriseus*). Data included the following standard fields: dataset name; kingdom, class and family name; scientific and common name or unique entity name; exotic (true or false); NSW status under the *Threatened Species Conservation Act 1995 (NSW)*; date first and last recorded; number indicated; estimate type (e.g. fewer than or greater than, exactly); observation type (e.g. seen, heard, scat, tracks); observer's (name); Scientific Licence number; location description; latitude and longitude (decimal degrees); and accuracy (in m). Note: entities include species, but also subspecies and generic categories (e.g. "small mammal", "Deer sp.", "Unidentified micro bat"). The number of entities therefore exceeds the number of accepted species. Each point–based record was then assigned attributes based on location, using the "Isectpntpoly()" tool GME (Beyer 2012). The following fields were added: NSW boundary (within NSW or outside NSW); IBRA v7 bioregion (bioregion name, see version 7 of Thackway and Creswell 1995); tenure at 14 August 2015 (conservation reserve name, e.g. Royal NP, and type, e.g. National Park, Nature Reserve, State Conservation Area etc., or "off park" if outside of a conservation reserves); wilderness areas (wilderness area name). In an additional column, coordinates were also rounded to the nearest 0.1° to allow the number of records per 0.1° grid to be counted and mapped (depending on location grid size is approximately 9–10 km horizontally and 11 km vertically). Coordinates used were "as held" which, depending on the accuracy of the recording and the accuracy of the cadastral layers used, may have incorrectly assigned values where records were near boundaries. This is particularly the case for earlier records collected before the use of GPS was widespread, or which were routinely assigned to the nearest grid intersect or town. Figures are therefore indicative. No validation of records was performed, due to the large number of records. Records were subset and cross tabulated in R (R core team 2015) to create the following summary tables and maps:

- Total number of fauna records held (this includes records outside of NSW), the number of records per fauna group, the number of entities identified (sub set by feral and native). The number of records per year was calculated (and displayed as a bar graph), showing the relative input of the top 10, out of 251 listed data providers. A separate graph shows these contributions spatially. Broadly similar bioregions were grouped into three super–regions. These regions were: a) Slopes bioregions (consisting of all data from Brigalow Belt South, New England Tablelands, Nandewar, NSW South West Slopes, Australian Alps and South Eastern Highlands); b) Far west bioregions (consisting of all data from Broken Hill Complex, Channel Country, Cobar Peneplain, Darling Riverine Plains, Mulga Lands, Murray Darling Depression, Simpson Strzelecki Dunefields and Riverina); c) Coastal bioregions (consisting of all data from South East Coastal Plain, South East Corner, South Eastern Queensland, Sydney Basin and NSW North Coast). The Sydney Basin Bioregion accounts for a large proportion of all records, so it was displayed separately from the remainder of the coastal bioregions.

- Number of records (in NSW) (by fauna group) in conservation reserves, off park and in wilderness areas. The average density of records was also calculated.

- Number of records (in NSW) of feral and native species and the proportion of records from each category that were recorded on protected areas.

- Number of records (in NSW) for each faunal class on and off park and the proportion of each category that are threatened species under the *Threatened Species Conservation Act 1995 (NSW)*.

- We analysed the records to reveal which species dominate the records system. This was done by counting the number of records for each entity for each of the following groups: birds, mammals, reptiles, amphibians, threatened species (NSW) and feral animals and listing the top 10 entities (and the number of records) in each group.

- A summary table, indicating how many protected areas (subsets being National Parks, Nature Reserves, State Conservation Areas and other protected areas) have: no records, 1–10 records, 10 to 1000 records, 1,000 to 10,000 records and 10,000+ records.

- The protected areas were ranked by the number of records, and the protected areas were listed alongside the number of records.

- The number of records per bioregion and the percentage of the records within each bioregion occurring within protected areas were calculated. The number of protected areas within each bioregion with and without fauna records was also calculated.

- The number of records per park vs the reserve size was graphed, indicating the reserve type National Park, Nature Reserve or other (which includes all conservation areas not otherwise accounted for).

- Cumulative number of entities per bioregion, and for selected National Parks, over time, was plotted to show the rate of the accumulation of knowledge and the impact of various initiatives, such as new datasets.

- The number of protected areas in which each group was recorded was calculated and summarised. The groups were: NSW threatened species (Critically Endangered, Endangered, and Vulnerable), protected species (native species that are not threatened) and exotic (also called feral and invasive) species. A list of threatened species without records on protected

areas and a list of threatened species recorded only in protected areas were also compiled. The data were processed in the following fashion to produce a set of recent records which contained species (useful entities, *i.e.* recognisable subspecies or some other taxonomic category other than a full binomial species name) to examine the degree to which terrestrial protected areas protect threatened species. Records older than 1990, or those which fell outside of mainland NSW, were not included, *i.e.* marine mammals (whales and dolphins), marine turtles and sea snakes were not included. Marine birds (*e.g.* albatross, petrels) were included in the data set. Any entity with the following text "unidentified", "sp." or "/" (this usually denotes two similar species *e.g.* musk/rainbow lorikeet) was not included.

Mapping

Records, rounded to the nearest 0.1 decimal degree, were used to plot the density (number of records per 0.1° cell) of bird, mammal, amphibian, reptile and invertebrate records. The density of fauna records submitted under Scientific Licences (all fauna records) was plotted in the same manner.

Rates of accumulation of protected areas

A graphical representation of the accumulation of protected areas from the first National Park (Royal National Park) was undertaken using official records within National Parks and Wildlife Service. The graphical material is divided at the point of 1967, which is the date of the passage of the *National Parks and Wildlife Act 1967* (NSW) and the formation of the NSW National Parks and Wildlife Service.

Rates of accumulation of fauna records

The fauna of NSW considered here are native and introduced mammals, birds, amphibians and reptiles within mainland NSW. While we limited the search to terrestrial areas, some marine fauna records occur on areas mapped as land (due to vagrancy, stranding, or imprecise geographical locations provided by the observer). Invertebrates were first considered when listed as threatened species following the passage of the *Threatened Species Conservation Act 1995*. The rate of accumulation of both fauna records and of the number of species in relation to the growth in the accumulation of area of National Parks was plotted. Species here refers to conventionally accepted binomial species only (as opposed to entities used above). Where a species has multiple subspecies these were grouped into a single species, which was counted only once. This comparison was undertaken to test whether there was a clear relationship between the accumulation of parks and reserves and the accumulation of records of fauna and species. This issue is central to the discussion of National Parks and Nature Reserves for conserving the State's wildlife.

For each comparison, the historical increase in parks' estate (in square km) was shown together with the rise in animal counts over the same time period. To best show the association between the measures, the lines are overlaid to the maximum possible extent. The scaling and origin of both lines were set to meet this criterion. This means that the left axis (measuring area of parks estate) and the right axis (showing animal or species counts) do not necessarily have a common origin and the scaling will not be the same because the measurement units are completely different. Each graph has an associated linear transformation of square km into counts derived using least squares regression. The origin and scale of each axis can then be set to enable the optimum overlay display of the full record of park estate area and species counts.

Results

Scientific Licences

The total number of Scientific Licences over the 3.5 year period (2011–mid–2014) was 1,371, of which 826 were for fauna (Table 1). A licence can be for one individual or for a group of individuals. There were 668 licences for plants, thereby giving 123 licences for both fauna and plants. This does not include licences for native fauna kept as pets, nor does it include licences for native fauna where the issue is managing individuals that are pests, such as common brushtail possums *Trichosurus vulpecula* or kangaroos on farms, or licences issued for commercial harvesting of kangaroos. The question of brushtail possums has been examined by Matthews *et al.* (2004), the commercial harvesting of kangaroos by Lunney (2010), licences for native pests by Lunney *et al.* (2007) and pets in Lunney (2012a,b).

The tenure of the 826 licences for fauna were: 555 in protected areas and 613 in other tenures, primarily private land (Table 2). Many (374) of these licences were for both protected areas and non–protected areas, while 213 licences were issued strictly for National Parks and Nature Reserves and 239 were strictly off park or reserve.

Of the licences issued for fauna on park, the commonest category was for "all fauna" (215, *i.e.*, 39%), with invertebrates (101, *i.e.* 18%) being the highest other category (Table 3). Off park, there were 613 licences issued, and given that the total is 826 licences, it shows a considerable (81%) overlap between licences that were

Table 1. Total number of scientific licences issued between 2011 and mid 2014 showing the type of activities licensed. The proportion (%) of total licences is indicated in brackets. Individual licences may cover multiple categories.

Total number of licences	1371
Fauna (excluding captive animals)	826 (60%)
Plants (including bush regeneration)	668 (49%)
Abiotic sampling (e.g. water, air, soil, leaf litter)	120 (9%)
Captive animals (education)	57 (4%)

for research both on and off park. There is no licence requirement for invertebrates off parks and reserves, thus a comparison of licences that cross tenure from private to public land is confined to vertebrates.

The top 10 most studied National Parks and Nature Reserves are shown by the number of licences (Table 4). The size of the reserve (km^2) and the density of licences allow comparisons between reserves of different sizes. Selection by researchers as to where they undertake their work within National Parks and Nature Reserves shows some striking preferences, with Kosciuszko National Park having the most licensed researchers (n = 58). When the licences per km^2 are examined, Sydney Harbour National Park is the standout area (Table 4). What is notable is that Nature Reserves attract fewer licensed researchers, with Macquarie Marshes Nature Reserve the most popular, with seven Scientific Licences. The tiny Brunswick Heads NR, at 2 km^2, has the highest density of licences at 2.2 licences per km^2. Nature Reserves were initially set up as Faunal Reserves, under the *Fauna Protection Act 1948* (NSW), for research and education. However, current usage, based on the number of licences issued, does not substantially reflect this aspiration, although the density of fauna records in Nature Reserves (40.6 per km^2) is higher than any other land category, indicating their utility to researchers. Licensed researchers do use the Nature Reserves near Sydney (Muogamarra Nature Reserve (n = 6), Dharawal Nature Reserve (n = 6), Towra Point Nature Reserve (n = 4).

The distribution and the number of Scientific Licences within protected areas show a heavy bias to the eastern strip of the State, with a greater clustering for the area around Sydney and the north coast (Figures 2, 3 and 4). The distribution of the licences for invertebrates shows an intense concentration along the eastern edge of the State (Figure 3). In both instances (vertebrates and invertebrates) this partly reflects the concentration of parks and reserves on the coast and Great Dividing Range. All maps reflect a close proximity of licences to human population centres, universities and research institutes, as is evident with the clustering in Figure 4.

Atlas records

Total number of fauna records held and annual variation in reporting

Table 5a shows the number of entities (*e.g.* species, subspecies or groups of species) identified (n = 2,441), and the total number of records of these entities (n = 8,847,490), in the Atlas (as of 14 August 2015), while Table 5b shows the number of conventionally accepted species. The Atlas records for all available data subsets by animal category and by tenure are shown in Tables 6a and 6b (NSW records only). Figure 5 shows the number of records per year in the Atlas. It particularly displays the variation in number of records per year. Figure 6 shows the different sources of data in the Atlas and reveals striking differences among the years. The pattern of recording records has not been consistent over the years (Figure 6). The most obvious influence is the inclusion of what is now the BirdLife Australia Bird Atlas project, which was first undertaken in (Atlas 1) 1977–1981, and then resumed (as Atlas 2) in 1998 (see Barrett *et al.* 2007). The Bird Atlas program alone has contributed 48% of all fauna records in the OEH Atlas. Other data–rich contributions are a state–wide community–based wildlife survey in 2006 (Lunney *et al.* 2009, 2010), the bird and bat banding scheme (6% of records) and WildCount from 2012 which uses camera trapping, *i.e.* cameras near tracks that are triggered when an animal passes (Meek *et al.* 2014), within protected

Table 2. Tenure shown on scientific licences for fauna study. Total number of licences is 826. Some licences indicated multiple tenures, so the row total exceeds the number of licences issued. LLS = Local Land Service, CMA = Catchment Management Authority, LGA = Local Government Area, NPWS = National Parks and Nature Reserves plus the small area in other protected categories. * In this analysis NPWS Estate does not include Marine Park and Karst Area.

	NPWS Estate*	LGA	LLS/ CMA Region	Marine Park	Karst Area	Private Land	State Forest
# licences	555	81	52	13	8	613	59
% of total	67	9	6	1	1	74	7

Table 3. Breakdown of scientific licences by fauna group (non–fauna licences have been omitted). Many licences indicated "all fauna", these were typically from ecological consultants who conduct general fauna surveys, rather than focus on specific animals.

Tenure	"all fauna" (type not specified)	Mammal	Reptile	Bird	Frog	Vertebrate pest	Invertebrate	Fish (f'water)	Marine fauna	Total
On Park	215	73	36	60	45	14	101	2	9	555
Off Park	240	105	44	122	49	9	27	0	17	613
All Tenures	269	138	62	147	67	17	105	2	19	826

areas. Scientific Licences have slowly grown, and now make up 14% of all fauna records. In 2014 (the last year of data available at the time of writing this paper for the RZS forum) there are fewer records, because of a delay in submitting records.

Number and density of records (in NSW) (by fauna group) in conservation reserves, off park and wilderness

Included in Table 6a are the area of the State, the percentage of the State for each tenure, and the density of fauna records (per km^2). Within NSW the greatest numbers of records are of birds (n = 4,913,511), followed by mammals (n = 832,361). Birds and mammals comprise 81% of all records in the Atlas. The 6,070,769 Atlas records (within NSW) were divided by tenure type: National Parks held 1,118,204 records, while Nature Reserves held 386,755 records (Table 6b). Nature Reserves had a total of 40.6 records per km^2 versus 21.4 records per km^2 for National Parks. Wilderness has 178,819 records, which is 8.5 records per km^2, and without WildCount records, there were 139,414 records in wilderness areas. By calculation, 321,721, or 39% of a total of 832,361 mammal records, were from WildCount. The off park records total was 4,407,486 representing 72.6% of all records, with a density of 6.0 records per km^2.

Number of records (in NSW) of feral and native species and the proportion of records from each category recorded on conservation reserves

The distribution of taxa in the Atlas records by tenure shows a marked bias when dividing the animals into feral (*i.e.* exotic or invasive species) or native (Table 7). Feral animal records account for 4% (n = 221,846) of the total number of records of vertebrates, thus 96% of all records are of native species. Of the 221,846 feral species records, about a quarter (27.6%) are on park and reserve, although 50.7% of the records of feral mammals are on parks and reserves.

Number of records (in NSW) for each faunal class on and off park and the proportion of each category that are threatened species

When the number of vertebrate records were examined by taxon, most (n = 4,913,511) were of birds, representing 82% of all native vertebrate records in the Atlas (Table 6b, Figure 5). Of this total of native birds, 22.5% were recorded on a park or reserve (Table 7). For native mammals, 58% of all records were on a park or reserve (Table 7).

The distribution of records according to tenure is shown for each of the four classes of vertebrates (Table 8). Of the grand total of fauna records within NSW, 6.8% are of threatened species. By land tenure, threatened

Table 4. Ten most studied National Parks (top) and Nature Reserves (bottom) by number of licences issued and the density of licences within each tenure type. Note, many licences indicated "all parks and reserves with approval", as these licences did not specify an individual reserve, these figures are likely to underestimate the number of licenced activities per reserve.

National Park	# licences	Area km^2	Licences/ km^2
Kosciuszko National Park	58	6896	0.01
Myall Lakes National Park	34	479	0.07
Ku–ring–gai Chase National Park	32	155	0.21
Blue Mountains National Park	25	2687	0.01
Royal National Park	24	153	0.16
Wollemi National Park	20	5015	0.00
Morton National Park	20	1993	0.01
Sydney Harbour National Park	16	4	4.12
Barrington Tops National Park	14	768	0.02
Nature Reserve	**# licences**	**Area km^2**	**Licences/ km^2**
Macquarie Marshes Nature Reserve	7	195	0.04
Muogamarra Nature Reserve	6	26	0.2
Dharawal Nature Reserve	6	4	1.6
Brunswick Heads Nature Reserve	5	2	2.2
Yathong Nature Reserve	4	1131	0.0
Tyagarah Nature Reserve	4	9	0.5
Towra Point Nature Reserve	4	6	0.6
Lake Innes Nature Reserve	3	34	0.1
Limpinwood Nature Reserve	3	29	0.1
Billinudgel Nature Reserve	3	7.9	0.4

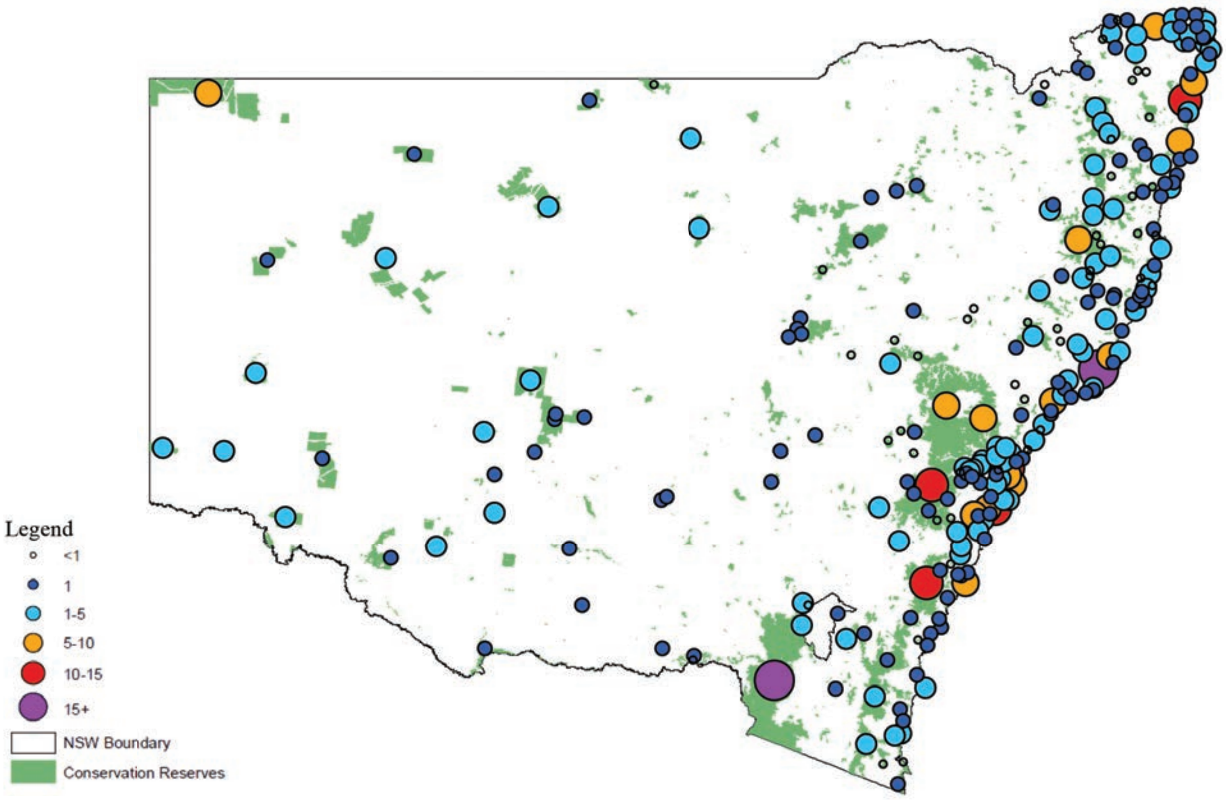

Figure 2. The distribution and concentration of Scientific Licences in NSW for vertebrates 2011 to 30 June 2014 within conservation reserves, each symbol represents a unique conservation reserve. Conservation reserves are protected areas and include National Parks and Nature Reserves.

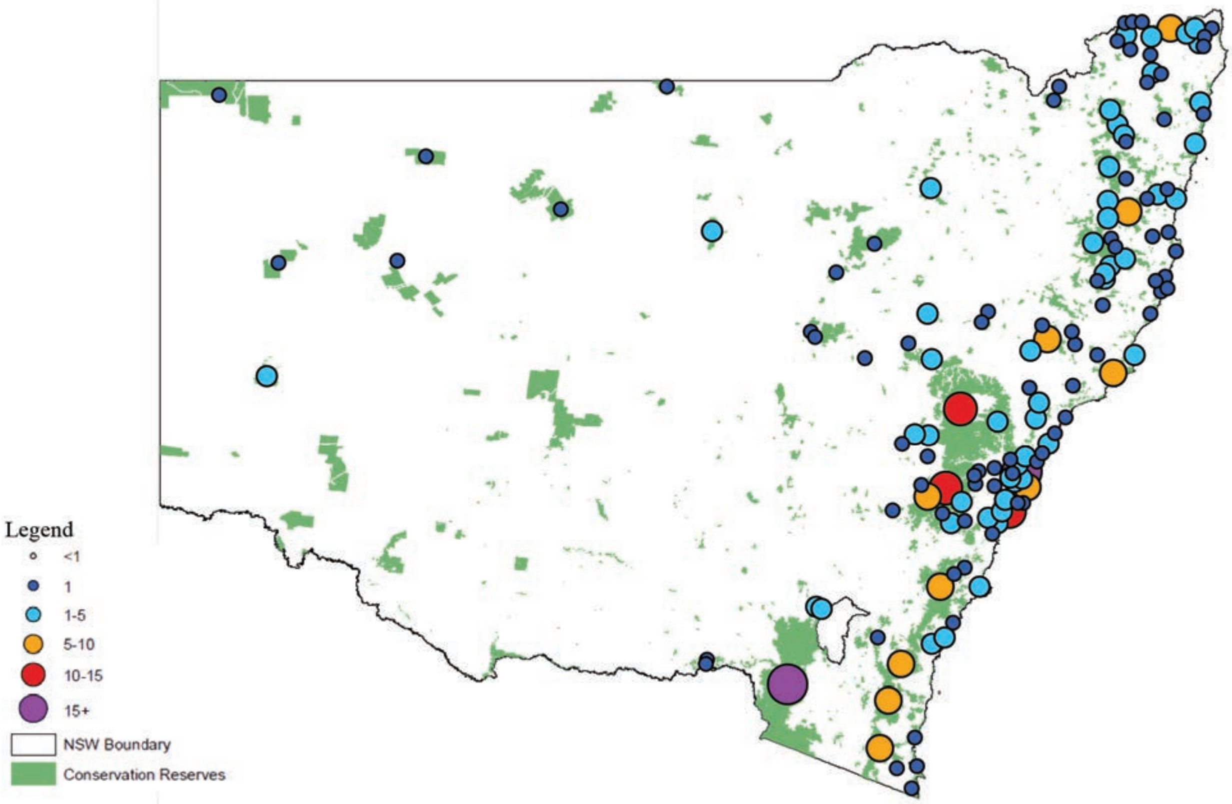

Figure 3. The distribution and concentration of Scientific Licences in NSW for invertebrates 2011 to 30 June 2014 within conservation reserves. Each symbol represents a unique conservation reserve. A licence is not required to study invertebrates outside of conservation reserves. *i.e.* protected areas, principally National Parks and Nature Reserves.

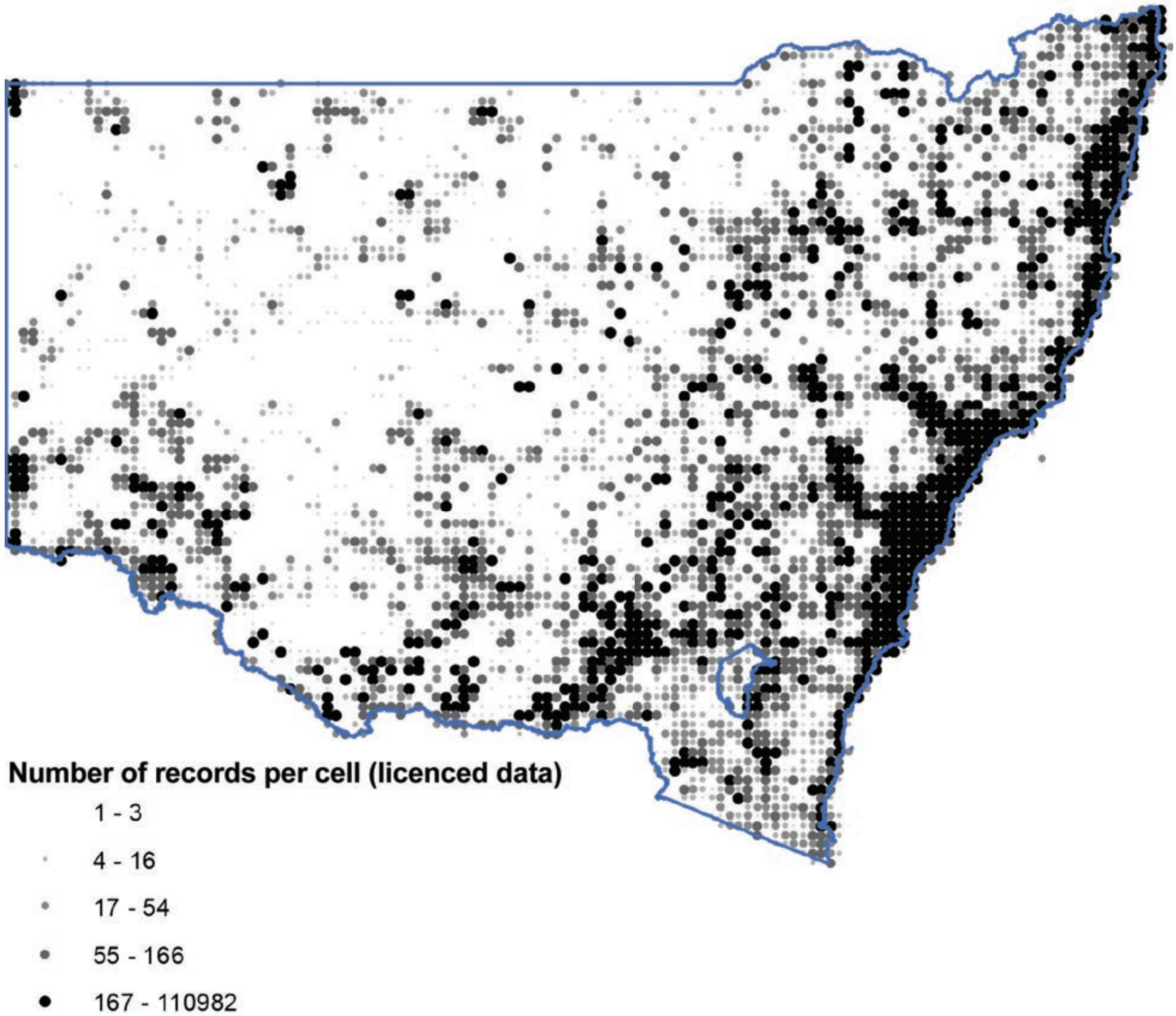

Figure 4. Density of records submitted from licence holders (all fauna) to the NSW Wildlife Atlas as of 30 June 2014 (unlike Tables 1–4 this includes data before 2011). Grid size is 0.1 decimal degrees. Classification was performed using 5 quantiles.

species records show the same percentages on and off park (6.8% in both cases). The largest contrast between on park and off park occurs with the mammals, where 24.2% of all mammal records off park are threatened species, whereas only 8.2% of mammals reported on park are threatened species. What is striking is the fact that around a quarter (24.0% off park and 26.2% on park) of all frog records are of threatened species, regardless of tenure. Most threatened species had records in a park or reserve, and those that did not were species with very few records, and they primarily occurred in the western part of the State where there are few parks or reserves.

Most commonly reported birds, mammals, reptiles, amphibians, threatened species (NSW) and feral species

Analyses of the Atlas records showed a high recording rate for some species, most noticeably the swamp wallaby *Wallabia bicolor* (n = 171,258, Table 9), which was about four times greater than the common brushtail possum (n = 44,056). The swamp wallaby records from WildCount dominate (n = 153,489 or 90% of all records for this taxon), they also comprise 2.5% of the total number of mammal records in the Atlas. The swamp wallaby is not a threatened species, so its high recording rate as a non–threatened species sharply reduces the calculated percentage of threatened species in parks and reserves. When the records system is examined for the most commonly reported species, mammals and birds dominate. For macropods (mammals), the three most common were the swamp wallaby, eastern grey kangaroo *Macropus giganteus* (n = 37,343) and red–necked wallaby (n = 30,863). These three species sum to a total of 239,464, which is 3.8% of the total number of records in the Atlas. In contrast to the mammals, reptiles is the vertebrate class least represented in the Atlas. The total number of reptile entries in the Atlas, 169,048, was 2.8% (*i.e.* equal to the number of swamp wallaby records). The three most common reptile species, as shown in Table 9, comprise 15% of the total number of reptiles in the Atlas. Only 2 of the 40 species listed are threatened. In comparison with the other taxa,

Table 5a. Total number of records and number of feral and native entities for each fauna class within the NSW Atlas of Wildlife (as of 14 August 2015), this include records for jurisdictions outside of NSW.

Class	#records	% of total	# of native entities identified	# feral entities identified
Fish	2,454	0.03	71	9
Amphibian	165,793	1.87	122	1
Bird	7,536,793	85.19	929	40
Mammal	912,627	10.32	307	35
Reptile	215,866	2.44	392	5
Invertebrate	6379	0.07	608	15
Unknown	7578	0.09	12	0
Grand Total	8,847,490	100	2441	105

Table 5b. Total number of species for each fauna class within the NSW Atlas of Wildlife (as of 14 August 2015) within and Parks and reserves and within the mapped terrestrial area of NSW. This does not include records for jurisdictions outside of NSW. Some marine species were included where records appeared on land. Sub species were grouped into binomial species. Note there are 174 extant species of mammals (Van Dyck *et al*. 2013), >535 species of birds in NSW (Cooper *et al*. 2016), 222 species of reptile (Cogger 2014) and 81 frogs (Cogger 2014). The differing totals here reflect inclusion of taxonomic relics, inclusion of marine species (e.g. sea snakes), differing availability of records, extinct species, misidentifications, vagrants or records not supported by a museum specimen. This table is not intended to be a comprehensive overview of the states fauna rather a summary of available information and these difference reinforce the need to interrogate data before they are used.

On park	Amphibia	Aves	Mammalia	Reptilia
Number of species	82	531	178	226
All tenures number of species	86	604	206	256

Table 6a. Area of NSW by tenure, propotion of the state occupied by each tenure class and density of fauna records within each tenure class. "On park" compromises NR, NP, Other terrestrial protected area and Wilderness. (Note: wilderness is declared over NPs and NRs and is thus within the "on park" total.

Tenure	Area (Ha)	% of state	Records km^{-2}
On park	7114503	8.9	23.4
NR	951531	1.2	40.6
NP	5236657	6.5	21.4
Other terrestrial protected area	926315	1.2	17.1
Wilderness	2097109	2.6	8.5
Off park	72949697	91.1	6.0
Total	**80064200**	**100**	**7.6**

Table 6b. Number of fauna records within NSW per tenure type for all fauna classes. All the figures NR, NP, Other terrestrial areas and Wilderness are within the "On park" total.

Tenure	Frogs	Birds	Mammals	Reptiles	Vertebrate total	Invertebrate	Grand total
On park	32819	1090390	475776	63613	1662598	885	1663483
NR	3789	255461	115643	11654	386547	208	386755
NP	24853	742037	305451	45256	1117597	607	1118204
Other terrestrial protected area	4177	92892	54682	6703	158454	70	158524
Wilderness	3678	104745	61471	8899	178793	86	178879
Off park	119272	3823121	356585	105435	4404413	2873	4407286
Total	**152091**	**4913511**	**832361**	**169048**	**6067011**	**3758**	**6070769**

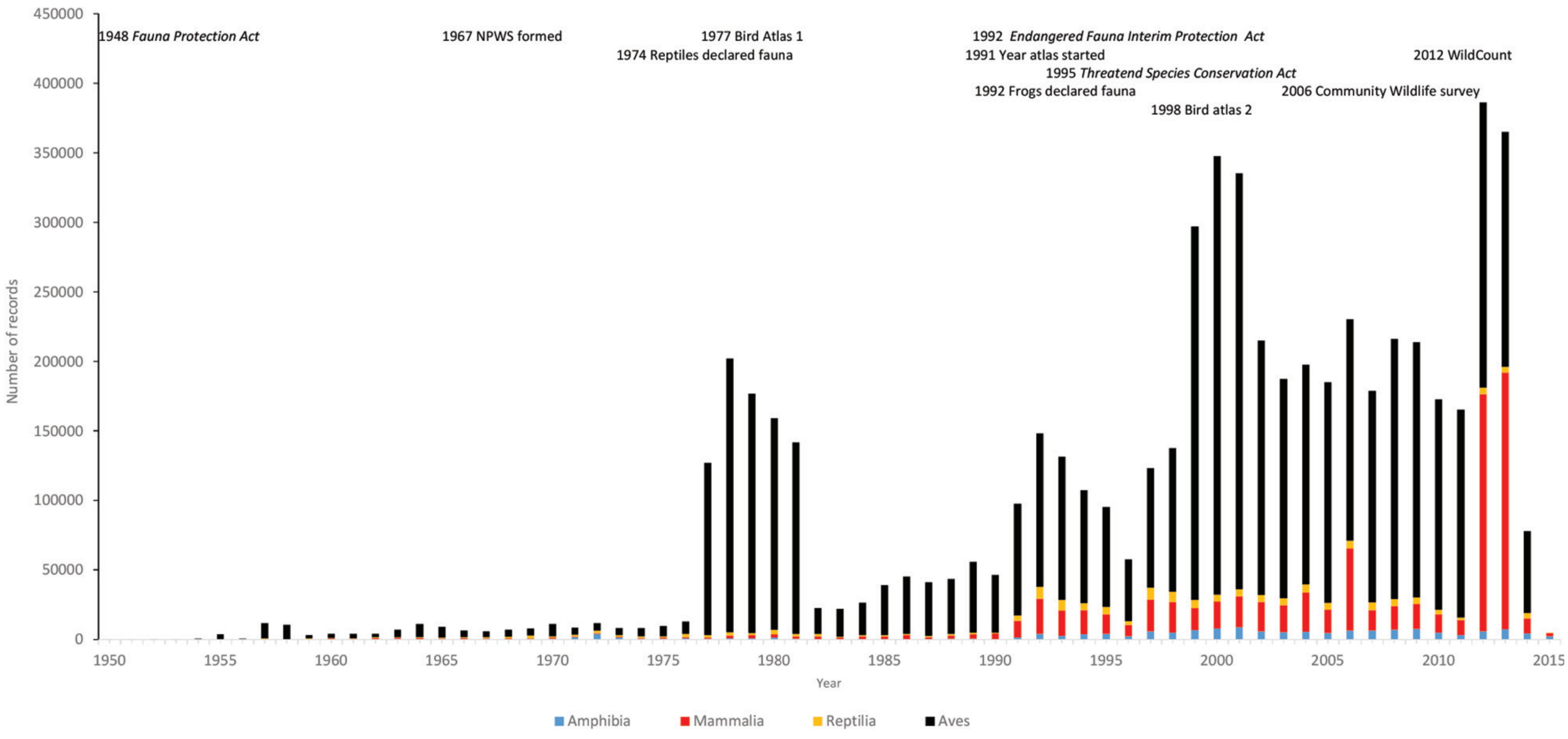

Figure 5. Number of fauna records in the Wildlife Atlas per year by class. Significant milestones are noted.

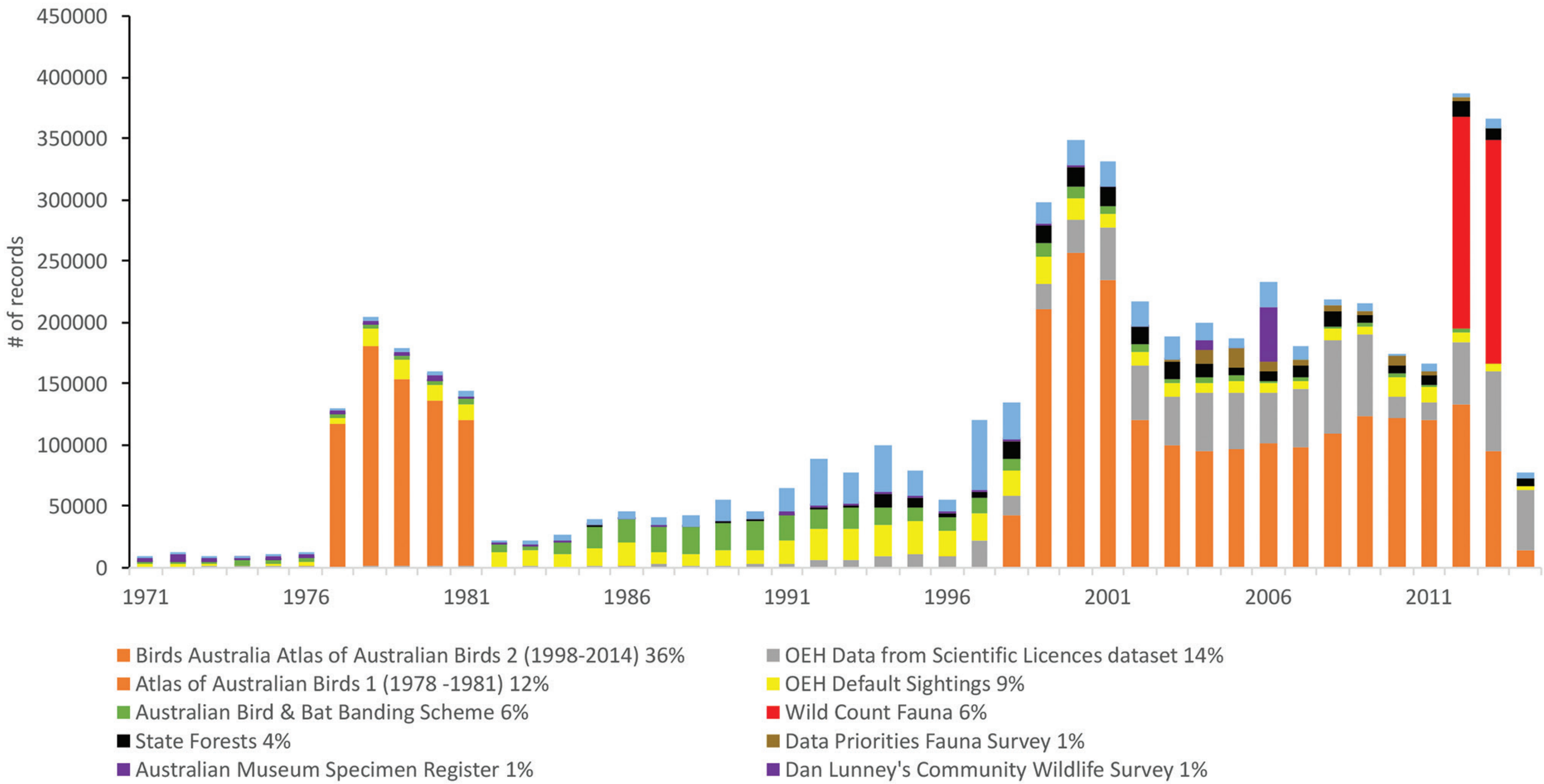

Figure 6. Number of fauna records in the Wildlife Atlas per year (from 1971 onwards) by provider for the top ten providers. The top ten providers account for 91% of all records. "Other" includes the remaining 241 providers. The proportion of the total records from each source is noted.

Table 7. Number of atlas records of native and feral species (by taxon) by tenure type. The percentage of records for each group that was recorded within a park or reserve is also shown.

	Number of records per taxon in the atlas	% of records on park and reserve
All feral records	**221846**	**27.6**
Amphibian	3695	17.8
Bird	118852	8.6
Mammal	99102	50.7
Reptile	27	0.0
Invertebrate	170	13.5
All native records	**5848923**	**27.4**
Amphibian	148396	21.7
Bird	4794659	22.5
Mammal	733259	58.0
Reptile	169021	37.6
Invertebrate	3588	24.0
Grand Total	**6070769**	**27.4**

Table 8. The fauna records off and on parks by class showing the percentage of records within each class that are of threatened species. On park refers to protected areas.

Tenure		# of records	Percentage (%) of total records for each class that are threatened species
Off park	All off park records	4407286	6.8
	Amphibian	119272	24.0
	Bird	3823121	4.7
	Mammal	356585	24.2
	Reptile	105435	2.6
	Invertebrate	2873	56.7
On park	All on park records	1663483	6.8
	Amphibian	32819	26.2
	Bird	1090390	5.9
	Mammal	475776	8.2
	Reptile	63613	2.8
	Invertebrate	885	42.3
	Grand Total	**6070769**	**6.8**

reptiles have a particularly low recording rate, with the most reported reptile, dark–flecked garden sunskink[13] *Lampropholis delicata* having only 13,627 records. Frogs a have a higher rate of records than reptiles, but they are still a considerably under–reported taxon in the Atlas. In summary, there is a highly skewed distribution among the taxa in the Atlas system, both among and within vertebrate classes.

A similar bias occurs in the reporting of feral species, notably the rabbit with a low (n = 9,042) record for what is one of Australia's greatest rural pests. In fact, the low number allows the suggestion to be made that the animals are so common that they are not reported. The fox, with 39,463 records, is the highest ranking because of two data sources – WildCount (n = 15,138) and the 2006 community wildlife survey by Lunney *et al.* (2009) (n = 13,263). Again, this highlights that the selection of sampling techniques is a major influence on the records, and it might be noted that both of these programs are OEH, so there was a predisposition for OEH staff to record their data in the Atlas, particularly if the data are recorded electronically, such as the camera and community surveys in these two examples.

Number of records in protected areas.
Most National Parks had between 1,000 and 10,000 records, while most Nature Reserves had between 100 and 1000 records (Table 10). Only 32 National Parks had more than 10,000 records.

13 The common names here are those used in the Atlas scheme. *Lampropholis delicata* is commonly known as the delicate skink or garden skink.

Table 9. Most commonly reported fauna entities and the number of records in NSW for the four fauna classes and for threatened species (*Threatened species Conservation Act 1995*) and feral species. * = feral species [E] = endangered, [V] = vulnerable, [EP] =endangered population. Scientific and common names are as recorded in Bionet. Species are ranked in descending number of records.

Birds	Mammals	Reptiles	Amphibians	Threatened Species	Ferals
Australian Magpie *Cracticus tibicen* 98,771	Swamp Wallaby *Wallabia bicolor* 171,258	Dark–flecked Garden Sunskink *Lampropholis delicata* 13,627	Common Eastern Froglet *Crinia signifera* 19,245	Koala *Phascolarctos cinereus* [V] Mammalia 36,358	Fox *Vulpes vulpes* Mammalia 39,463
Superb Fairy–wren *Malurus cyaneus* 80,197	Common Brushtail Possum *Trichosurus vulpecula* 44,056	Pale–flecked Garden Sunskink *Lampropholis guichenoti* 6,238	Green and Golden Bell Frog *Litoria aurea* [E] 17,926	Brown Treecreeper (eastern subspecies) *Climacteris picumnus victoriae* [V] Aves 21,754	Common Starling *Sturnus vulgaris* Aves 33,382
Grey Fantail *Rhipidura albiscapa* 78,155	Fox *Vulpes vulpes* * 39,463	Lace Monitor *Varanus varius* 5,789	Brown–striped Frog *Limnodynastes peronii* 11,026	Glossy Black–Cockatoo *Calyptorhynchus lathami* [V,EP] Aves 19,641	Spotted Turtle–Dove *Streptopelia chinensis* Aves 19,284
Willie Wagtail *Rhipidura leucophrys* 73,772	Eastern Grey Kangaroo *Macropus giganteus* 37,343	South–eastern Morethia Skink *Morethia boulengeri* 5,497	Peron's Tree Frog *Litoria peronii* 9,151	Green and Golden Bell Frog *Litoria aurea* [E] Amphibia 17,926	House Sparrow *Passer domesticus* Aves 18,726
Laughing Kookaburra *Dacelo novaeguineae* 73,445	Koala *Phascolarctos cinereus* [V] 36,358	Eastern Water–skink *Eulamprus quoyii* 4,903	Eastern Dwarf Tree Frog *Litoria fallax* 7,678	Yellow–bellied Glider *Petaurus australis* [V,EP] Mammalia 16,732	Common Myna *Sturnus tristis* Aves 15,846
Grey Shrike–thrush *Colluricincla harmonica* 71,562	Common Wombat *Vombatus ursinus* 35,837	Copper–tailed Skink *Ctenotus taeniolatus* 3,864	Spotted Grass Frog *Limnodynastes tasmaniensis* 7,641	Grey–crowned Babbler (eastern subspecies) *Pomatostomus temporalis temporalis* [V] Aves 12,739	Dingo, domestic dog *Canis lupus* Mammalia 9,622
Magpie–lark *Grallina cyanoleuca* 71,310	Red–necked Wallaby *Macropus rufogriseus* 30,863	Red–bellied Black Snake *Pseudechis porphyriacus* 3,600	Lesueur's Frog *Litoria lesueuri* 4,537	Grey–headed Flying–fox *Pteropus poliocephalus* [V] Mammalia 11,187	Rabbit *Oryctolagus cuniculus* Mammalia 9,042
Pied Currawong *Strepera graculina* 70,633	Greater Glider *Petauroides Volans* 22,381	Eastern Water Dragon *Intellagama lesueurii* 3,395	Verreaux's Frog *Litoria verreauxii* 4,117	Flame Robin *Petroica phoenicea* [V] Aves 9,080	Rock Dove *Columba livia* Aves 7,339
Silvereye *Zosterops lateralis* 66,262	Brown Antechinus *Antechinus stuartii* 20,311	Three–toed Skink *Saiphos equalis* 3,289	Red–backed Toadlet *Pseudophryne coriacea* 3,868	Spotted–tailed Quoll *Dasyurus maculatus* [V] Mammalia 9,014	Eurasian Blackbird *Turdus merula* Aves 6,942
Yellow–faced Honeyeater *Caligavis chrysops* 65,039	Bush Rat *Rattus fuscipes* 18,246	Jacky Lizard *Amphibolurus muricatus* 2,990	Cane Toad *Rhinella marina* * 3,695	Varied Sittella *Daphoenositta chrysoptera* [V] Aves 8,893	Fallow Deer *Dama dama* Mammalia 6,455

Protected areas with most records.

The league table of protected areas (Table 11) shows that a few protected areas have large numbers of records, with Kosciuszko NP, Wollemi NP and Blue Mountains NP each having over 50,000 records.

Number of records per bioregion and percentage of records within each bioregion occurring within protected areas

At 1,654,338 records, Sydney Basin is the bioregion with the most records (Table 12). Within bioregions, the percentage of records on park, vs off park, ranges from 15% to 83%. Areas with a high proportion of protected areas (*e.g.* Australian Alps at 83% of records on park) can be compared to those with a low proportion of protected areas, such as the NSW south–western slopes, with only 19% of records on park (Table 12). The comparison between regions per year shows a strong bias in reporting, in particular, coastal areas (Figure 7). The NSW North Coast had 29 parks with no records, the highest of any bioregion. Many of these are small parks or islands (Table 12).

Number of records per park vs reserve size

Figure 8 shows the relationship between park type, park size and number of faunal records, showing that large areas in general have more records. National Parks tend to be larger and have more records.

Cumulative number of entities per bioregion and for selected National Parks

Accumulation of species (or more correctly entities) visually displays the lack of completeness of survey data. A steeply rising graph indicates that new entities are frequently being recorded, whereas a flattening graph indicates that most species in the area have been reported, or a lack of survey in that area. The latter cannot be distinguished from the former as survey effort has not been documented. Figure 9 shows the accumulation of records per bioregion for all species, and Figures 10–14 further break this down into the four fauna classes and invertebrates. In all cases, the graphs show little evidence of approaching a maximum. The first Bird Atlas (1978–1981) resulted in a steep increase in records in the late 1970s, the exception being the Sydney Basin. Here the increase is less obvious because many of the species that were reported in the first Bird Atlas had already been reported. These patterns in the eight well–known parks reveal the impact of the Bird Atlas, namely a steep section followed by a more gradual accumulation (Figure 15).

Table 10. Number of records per park for the 867 conservation reserves in NSW, subset by park type. "NP" = National Park, "NR" =Nature Reserve, "SCA"= State Conservation Area. "Other" includes Aboriginal Areas, Historic Site, Karst Conservation reserves and Regional Parks

# of records	NP	NR	SCA	Other	Total
0	4	51	18	16	89
1 to 10	2	35	7	5	49
10 to 100	11	96	18	11	136
100 to 1000	66	137	56	41	300
1000 to 10000	121	96	27	14	258
10000+	32	3	0	0	35

Summary of reporting pattern for NSW threatened species (Critically Endangered, Endangered, and Vulnerable), protected species (native species that are not threatened) and exotic species.

Of a total of 256 threatened species assessed, 14 threatened species did not have any Atlas records in protected areas (Tables 13, 14). One hundred and six Vulnerable species were recorded in 10 or more reserves, while only eight Critically Endangered species were recorded on 10 or more reserves. Many exotic species (20 out of a total of 64) were not recorded in the protected area system, while nine threatened species were only recorded within the protected area system (Table 15). Only 11 species were found in more than 500 protected areas (out of a possible 867 protected areas, see Figure 8). All of these were birds (grey shrike–thrush *Colluricincla harmonica*, black–faced cuckoo–shrike *Coracina novaehollandiae*, white–throated treecreeper *Cormobates leucophaea*, Australian magpie *Cracticus tibicen*, grey butcherbird *Cracticus torquatus*, laughing kookaburra *Dacelo novaeguineae*, eastern yellow robin *Eopsaltria australis*, rufous whistler *Pachycephala rufiventris*, spotted pardalote *Pardalotus punctatus*, grey fantail *Rhipidura albiscapa* and pied currawong *Strepera graculina*).

Table 11. Top protected areas as shown by number of fauna records in the NSW wildlife atlas.

Park	# of records
Kosciuszko NP	57451
Wollemi NP	57095
Blue Mountains NP	53719
Hunter Wetlands NP	32074
Yuraygir NP	23661
Royal NP	21941
Warrumbungle NP	21644
Barrington Tops NP	20908
Yengo NP	19949
Murray Valley NP	19772
South East Forest NP	19321
Lane Cove NP	16438
Oxley Wild Rivers NP	16364
Border Ranges NP	16069
Myall Lakes NP	15356
Sturt NP	15317
Coolah Tops NP	14396
Murrumbidgee Valley NP	14036
The Charcoal Tank NR	13981

Table. 12 Number of records per IBRA v7 bioregion (Thackway and Creswell 1995) and proportion of records in protected areas. Ordered by number of records in decreasing order. The number of reserves with nil records in each bioregion is shown.

Bioregion	Total	% on park	# of reserves without any records
Sydney Basin	1654338	27.4	14
South Eastern Queensland	686750	22.4	10
NSW South Western Slopes	553243	18.8	3
South Eastern Highlands	375112	35.4	16
Riverina	296734	18.1	0
Brigalow Belt South	249409	35.2	7
South East Corner	246366	29.5	1
New England Tablelands	239085	44.0	2
Darling Riverine Plains	181044	14.8	1
Cobar Peneplain	139019	25.1	3
Nandewar	133592	26.1	0
Murray Darling Depression	116939	30.3	0
NSW North Coast	108098	29.2	29
Mulga Lands	44909	19.5	0
Australian Alps	40808	82.5	0
Broken Hill Complex	33680	35.0	0
Channel Country	20476	42.1	1
Simpson Strzelecki Dunefields	8951	74.8	0

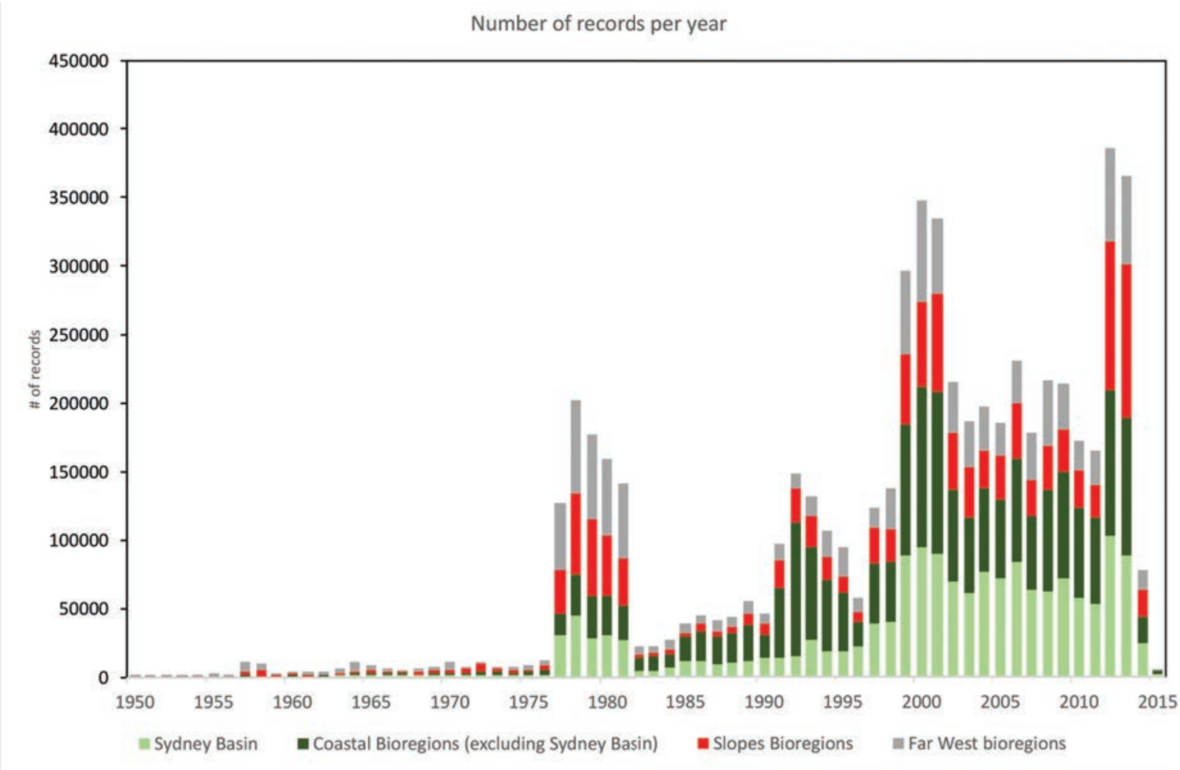

Figure 7. Number of records per year per bioregion group. Bioregions were grouped in the following manner: Slopes bioregions (consisting of all data from Brigalow Belt South, New England Tablelands, Nandewar, NSW South West Slopes, Australian Alps and South Eastern Highlands); Far west bioregions (consisting of all data from Broken Hill Complex, Channel Country, Cobar Peneplain, Darling Riverine Plains, Mulga Lands, Murray Darling Depression, Simpson Strzelecki Dunefields and Riverina), and Coastal bioregions (consisting of all data from South East Coastal Plain, South East Corner, South Eastern Queensland and NSW North Coast). Sydney Basin is a coastal bioregion but was displayed separately as this bioregion dominates the records system.

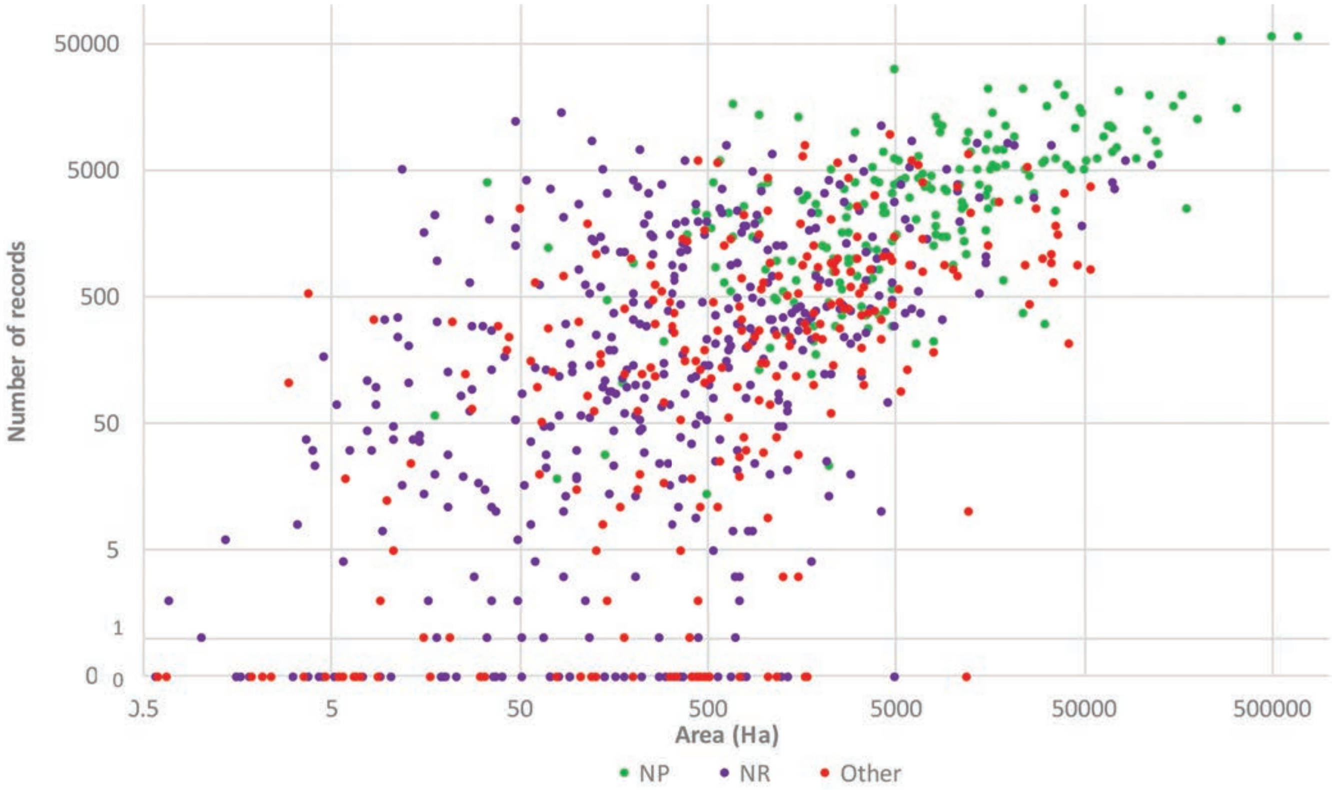

Figure 8. Relationship between park type, size and number of records. "NP" = National Park, "NR" = Nature Reserve while "Other" includes State Conservation Areas, Aboriginal Areas, Historic Site, Karst Conservation Reserves, and Regional Parks. Axes are log scale and the y axis is discontinuous (between 0 and 1) to allow zero values to be displayed with a log scale axis. At the time of analysis (14 August 2015) there were 202 National Parks (73.4% of National Parks and Wildlife Service estate by area), 418 Nature Reserves (13.3% by area) and 247 other reserves (13.3% by area).

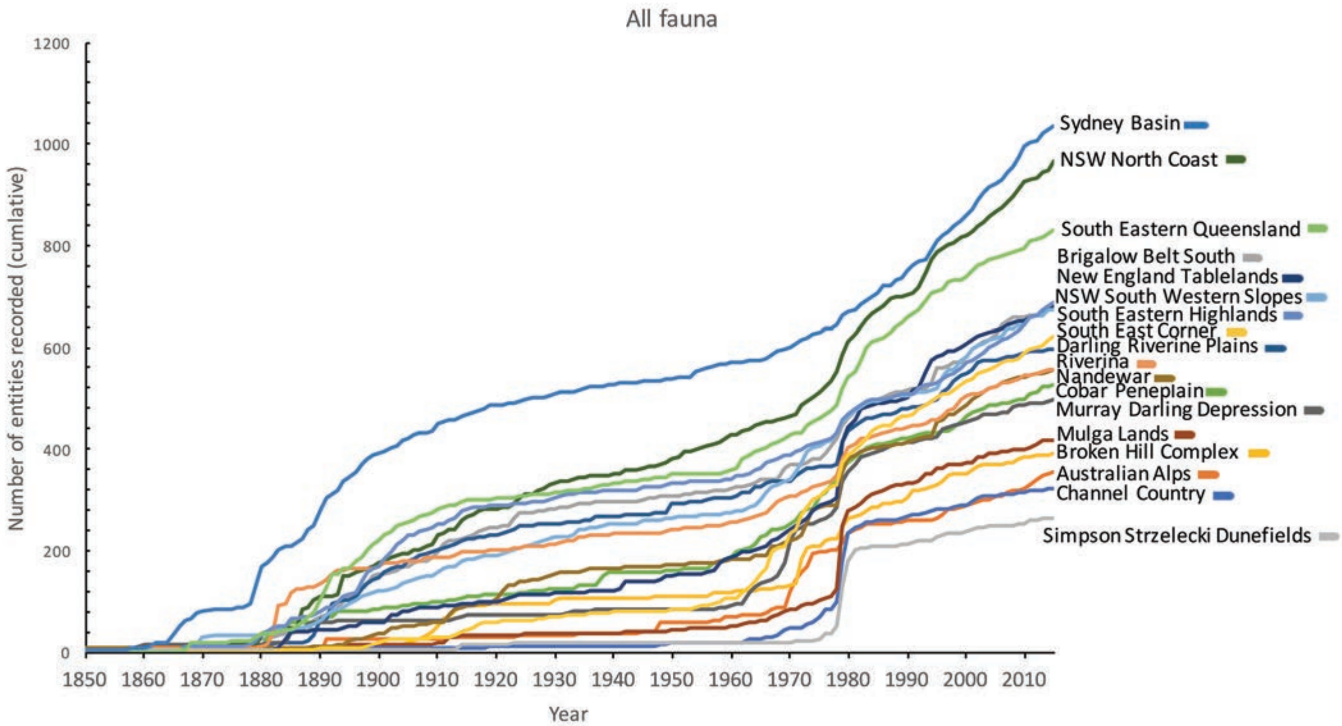

Figure 9. Accumulation of unique entities of all fauna over time per bioregion. In the atlas unique entities are primarily species but can include generic terms or be the result of taxonomic changes.

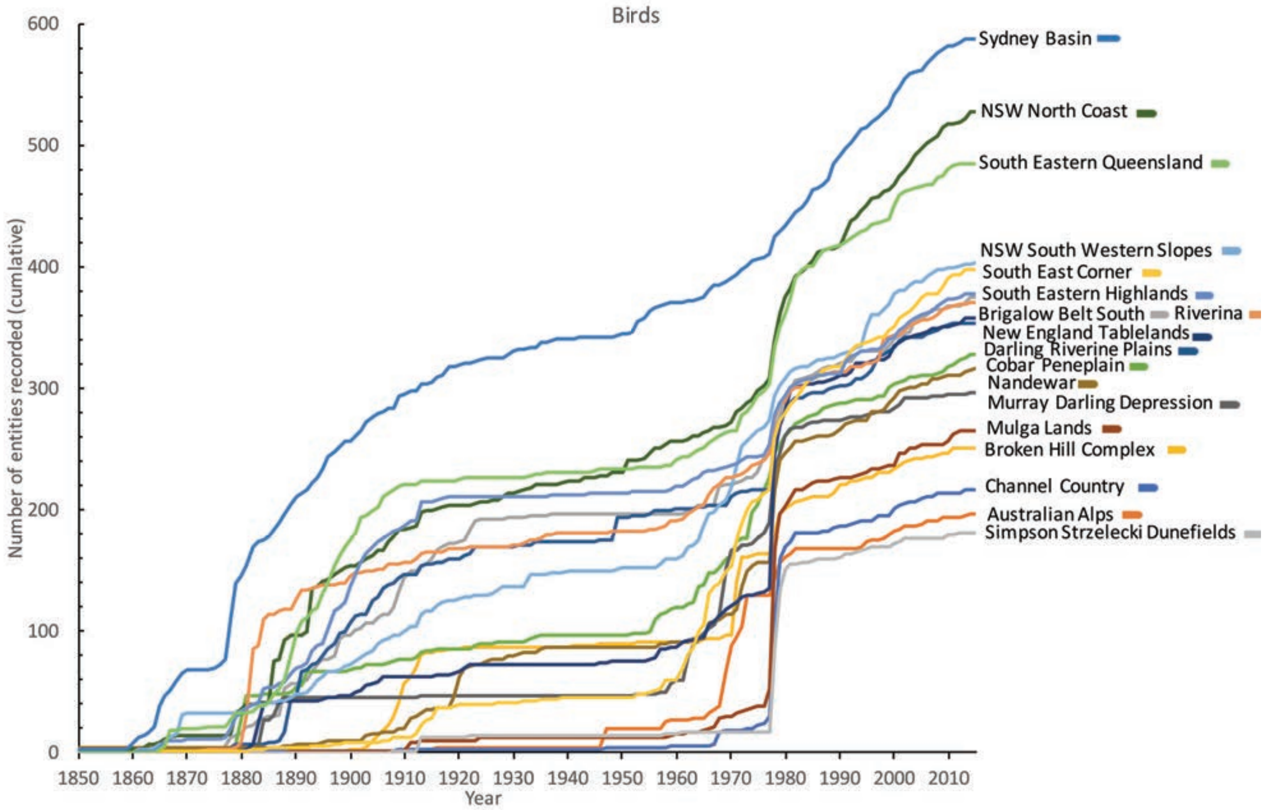

Figure 10. Accumulation of unique entities of birds over time per bioregion

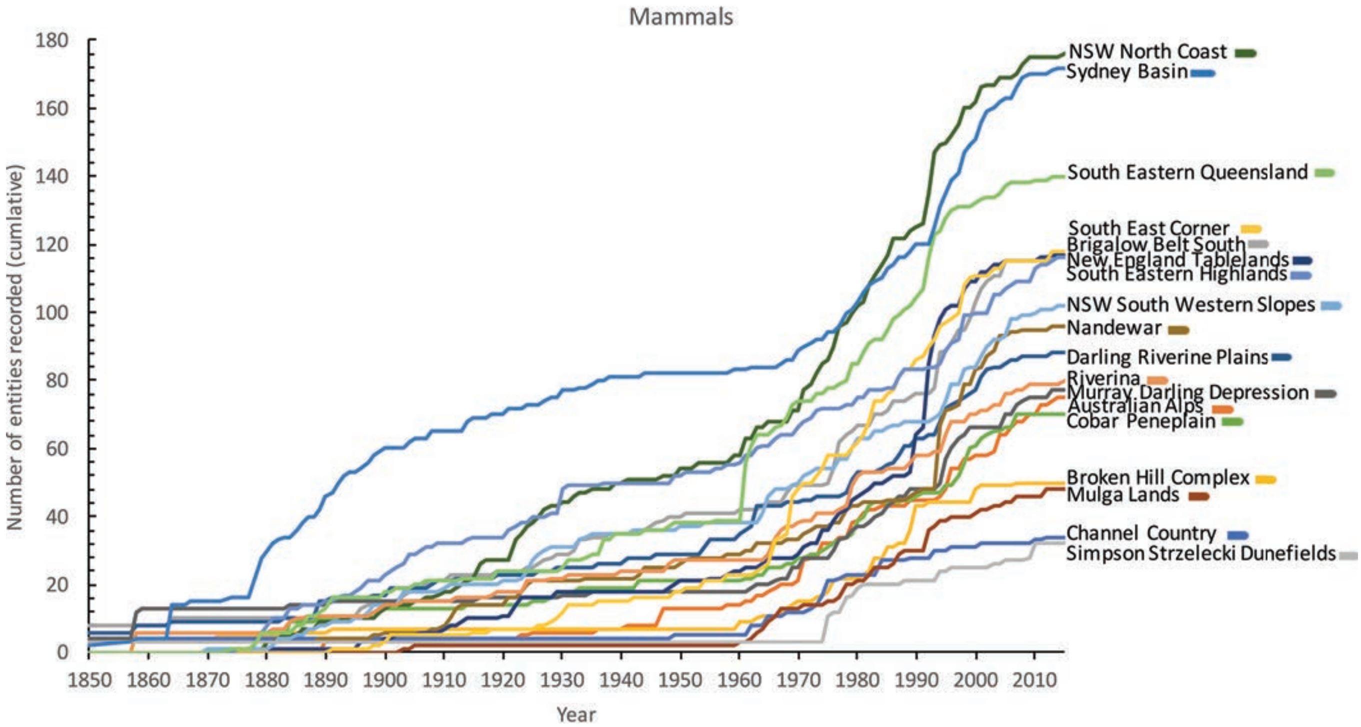

Figure 11. Accumulation of unique entities of mammals over time per bioregion

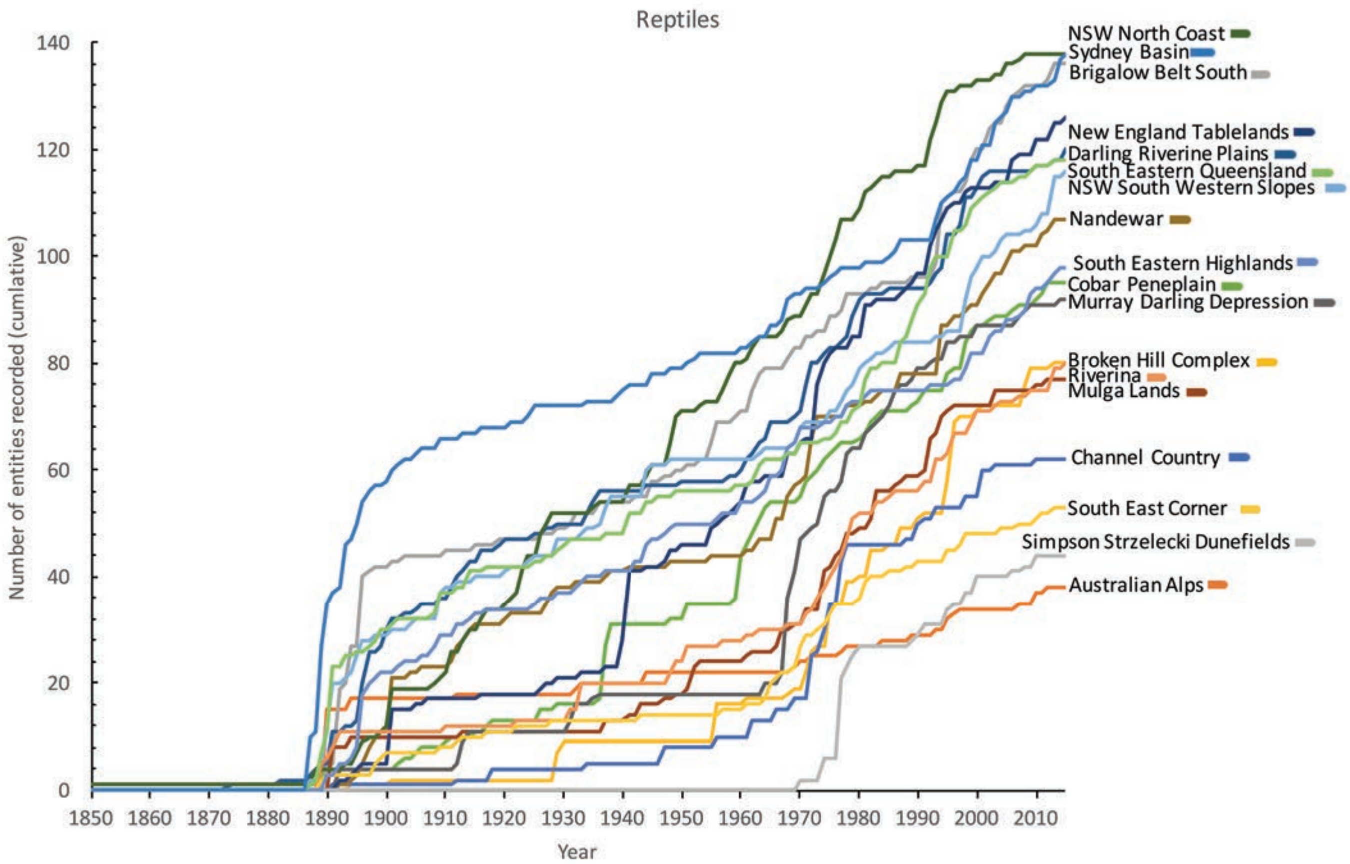

Figure 12. Accumulation of unique entities of reptiles over time per bioregion

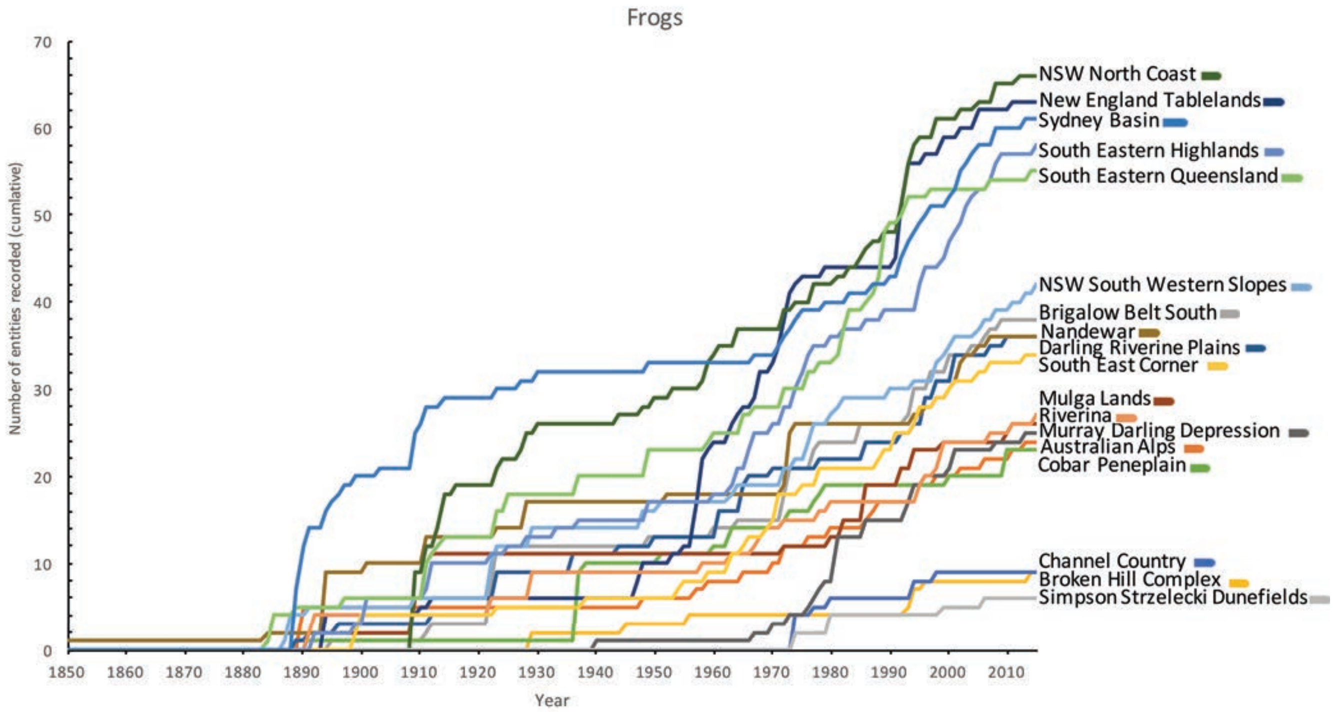

Figure 13. Accumulation of unique entities of frogs over time per bioregion.

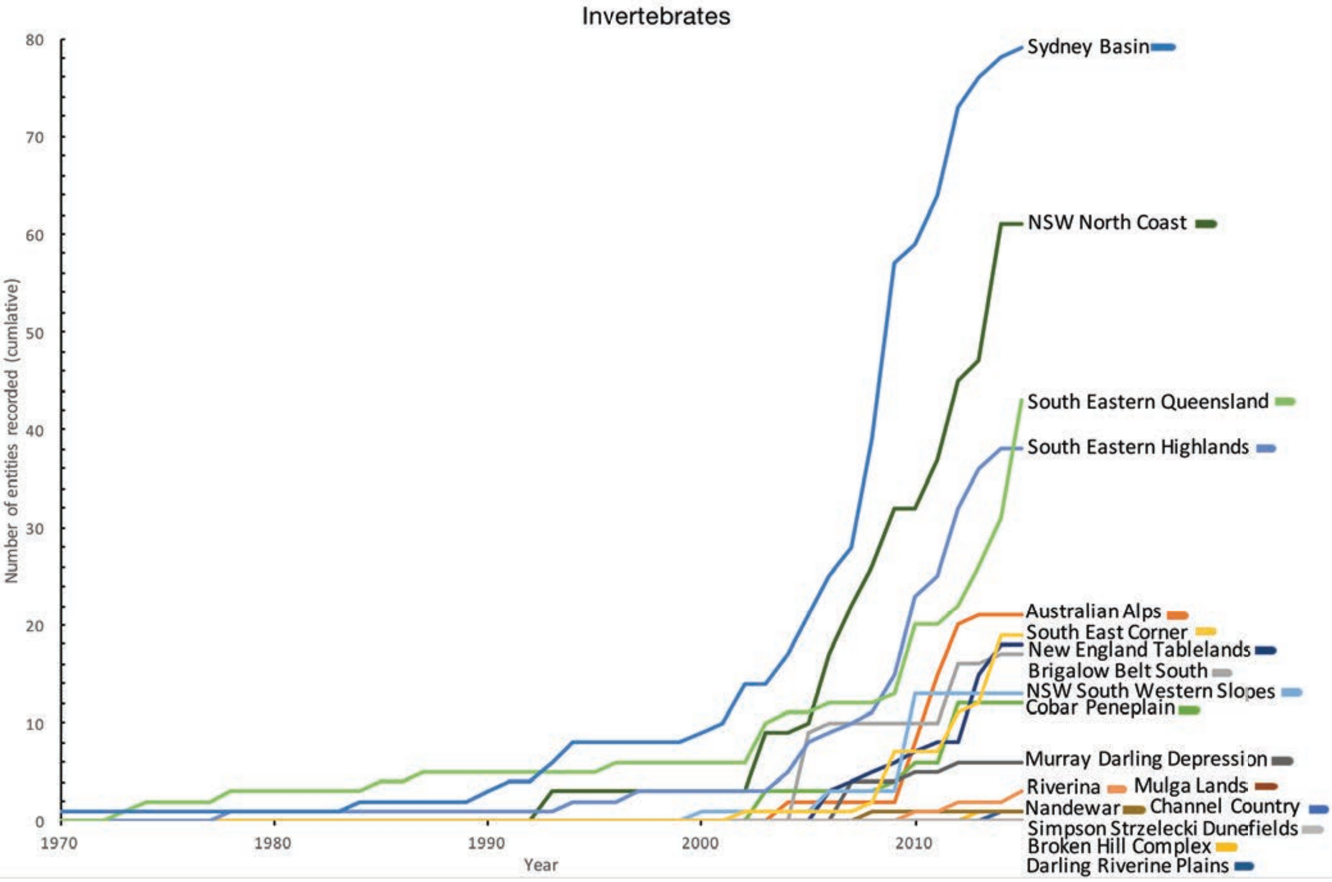

Figure 14. Accumulation of unique entities of invertebrates over time per bioregion.

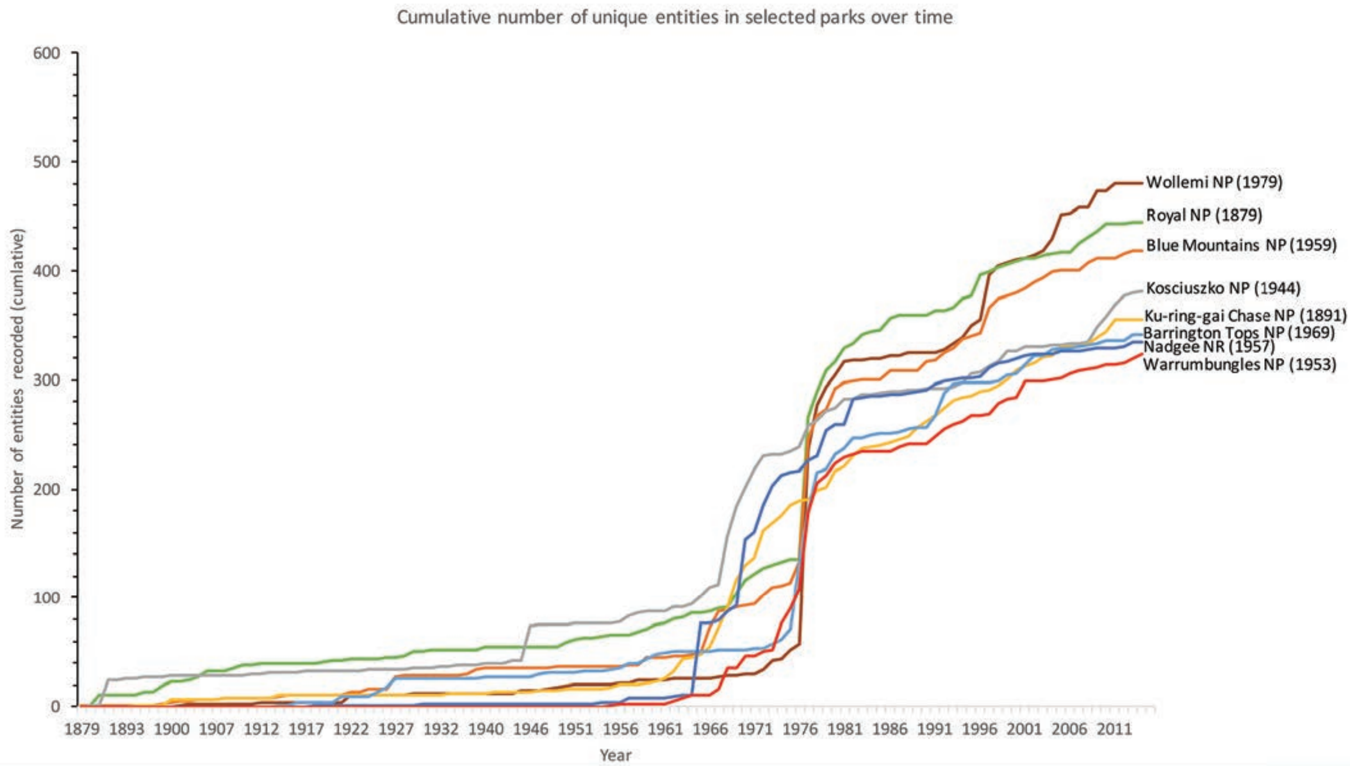

Figure 15. Accumulation of unique entities (all fauna i.e. birds, mammals, reptiles and frogs) over time within selected parks. The year of dedication is shown in brackets for each reserve.

Map–based data

The distribution of records from the Atlas shows a heavy clustering in the eastern portion of NSW, and a sparse distribution in the western half of the state (Figures 16, 17, 18, 19, 20 for birds, mammals, reptiles, amphibians and invertebrates respectively). In large measure, this reflects the heavier clustering of parks and reserves on the coast and ranges in the eastern part of the state (Figure 1). The maps of the distribution of all mammals, birds, frogs and reptiles in parks and reserves show a distinct patterning. This reflects an expanding range of survey techniques, such as camera trapping, acoustic monitoring and citizen science, in addition to established techniques, such as bird watching with binoculars.

Rates of accumulation of protected areas

Figures 21–25 present a graphical representation of the accumulation of protected areas from the first National Park (Royal National Park)[14] in 1879. The graphical material is divided at the point of 1967, which is the year of the passage of the *National Parks and Wildlife Act 1967* (NSW) and the formation of the NSW National Parks and Wildlife Service. Prior to that point, Nature Reserves were dedicated and managed by the Fauna Protection Panel, and the National Parks were managed by Trusts responsible to the Department of Lands. Further, since the area of National Parks overwhelms the area of Nature

14 It also corrects a minor error in Lunney (2014). In the graphs and tables in Lunney (2014), the dedication of Ku–ring–gai was recorded as 1961. This error arose from internal listing within NPWS. It should have been 1894. It is now correct in the current graphs.

Table 13. The number of NSW native vertebrate species in each category (Critically Endangered, Endangered, Vulnerable, Protected but not threatened or exotic) recorded in the subset of NSW species analysed. For each category, the number of species recorded in no protected areas (0), one protected area (1), three to nine protected areas (3–9) or more than ten protected areas (>10) is shown. For Critically Endangered species 43% (n=8) of Critically Endangered species are recorded in more than 10 protected areas, whereas for non–threatened protected species 64% (n= 536), or Vulnerable species 66% (n= 106) are recorded in more than 10 protected areas. [A] The number of species listed on threatened species lists (NSW) differs from the figure analysed as we exclude non–mainland records (e.g. Lord Howe Island), which also removes many marine species (whales, dolphins and marine turtles) from these totals. See Table 5b for the number of species known to occur in NSW.

Category	The number of species in 0, 1, 2, 3–9 or 10+ protected areas					Number of species [A]
	0	1	2	3–9	10+	
Critically Endangered	5	4	1	1	8	**19**
Endangered	10	13	8	19	26	**76**
Vulnerable	8	4	7	36	106	**161**
Protected (Native)	109	65	31	91	536	**832**
Feral	20	5	1	11	27	**64**

Table 14. List of threatened species with no records in protected areas, excludes whale, dolphins, marine turtles, extinct species and non–mainland records (e.g. Lord Howe Island). Records older than 1990 were not included, nor were species without any records after 1990. Black–throated Finch (southern subspecies) was listed as extinct in 2016 after analysis occurred.

NSW Status	Class	Family	Species	Common Name
Critically Endangered	Amphibia	Hylidae	*Litoria castanea*	Yellow–spotted Tree frog
Critically Endangered	Amphibia	Hylidae	*Litoria piperata*	Peppered Tree Frog
Critically Endangered	Insecta	Lycaenidae	*Jalmenus eubulus*	Pale Imperial Hairstreak
Endangered	Amphibia	Myobatrachidae	*Neobatrachus pictus*	Painted Burrowing Frog
Endangered	Aves	Maluridae	*Amytornis barbatus barbatus*	Grey Grasswren
Endangered	Aves	Estrildidae	*Poephila cincta cincta*	Black–throated Finch (southern subspecies)
Endangered	Insecta	Carabidae	*Nurus atlas*	Atlas Rainforest Ground–beetle
Endangered	Mammalia	Vombatidae	*Lasiorhinus latifrons*	Southern Hairy–nosed Wombat
Endangered	Reptilia	Elapidae	*Echiopsis curta*	Bardick
Vulnerable	Aves	Diomedeidae	*Diomedea gibsoni*	Gibson's Albatross
Vulnerable	Aves	Meliphagidae	*Lichenostomus cratitius*	Purple–gaped Honeyeater
Vulnerable	Aves	Psittacidae	*Neophema splendida*	Scarlet–chested Parrot
Vulnerable	Reptilia	Boidae	*Aspidites ramsayi*	Woma
Vulnerable	Reptilia	Elapidae	*Suta flagellum*	Little Whip Snake

Table 15. Threatened species recorded only on protected areas

NSW Status	Class	Family	Species	Common Name
CE	Amphibia	Hylidae	*Litoria spenceri*	Spotted Tree Frog
CE	Mammalia	Muridae	*Pseudomys desertor*	Desert Mouse
CE	Amphibia	Myobatrachidae	*Pseudophryne corroboree*	Southern Corroboree Frog
CE	Aves	Turnicidae	*Turnix melanogaster*	Black–breasted Button–quail
Endangered	Mammalia	Burramyidae	*Burramys parvus*	Mountain Pygmy–possum
Endangered	Reptilia	Scincidae	*Cyclodomorphus praealtus*	Alpine She–oak Skink
Endangered	Mammalia	Muridae	*Pseudomys delicatulus*	Delicate Mouse
Endangered	Reptilia	Typhlopidae	*Ramphotyphlops endoterus*	Interior Blind Snake
Vulnerable	Aves	Diomedeidae	*Diomedea antipodensis*	Antipodean Albatross

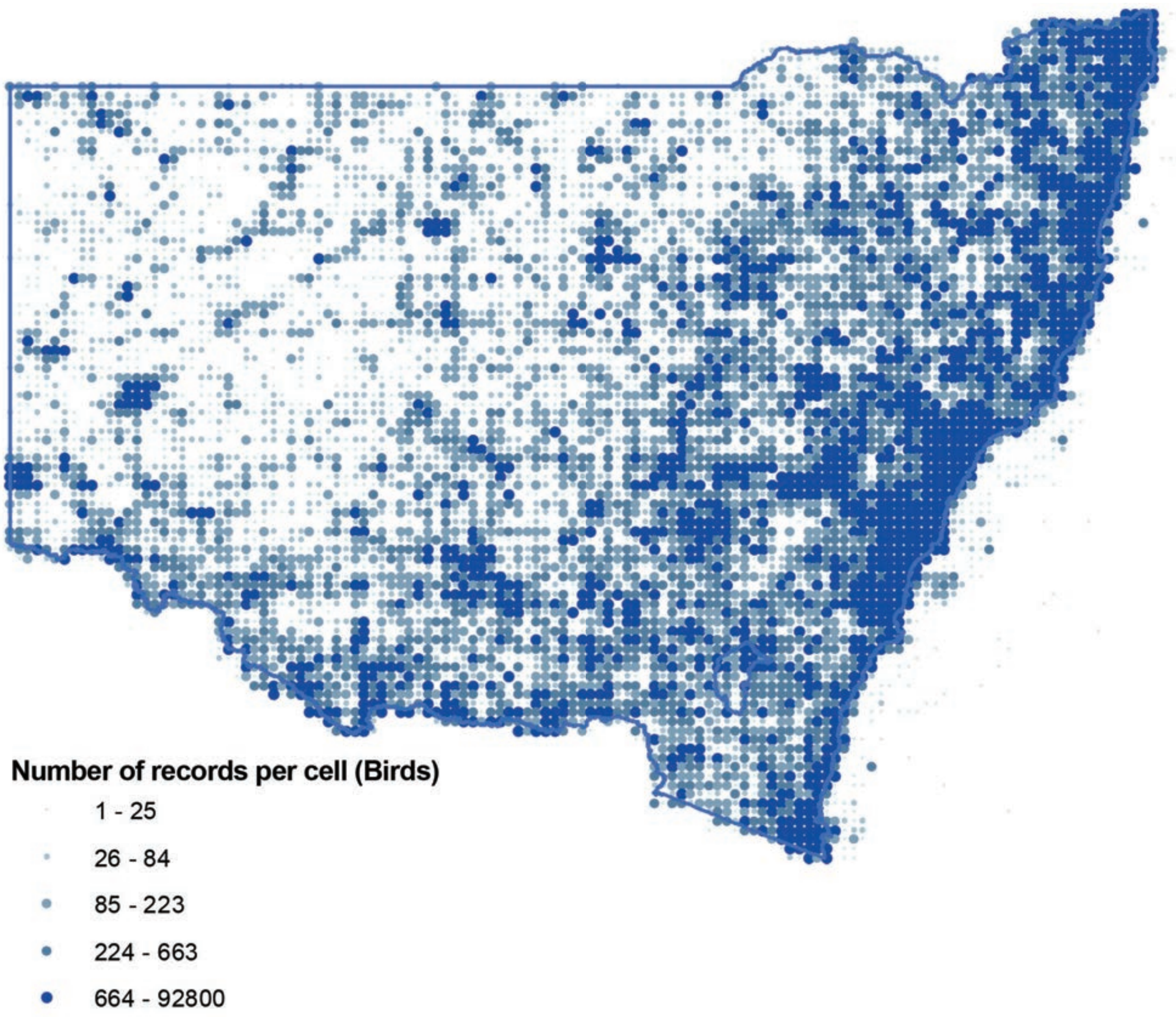

Figure 16. Bird record density map for the NSW Wildlife Atlas. Grid size is 0.1 degrees. Classification was performed using 5 quantiles.

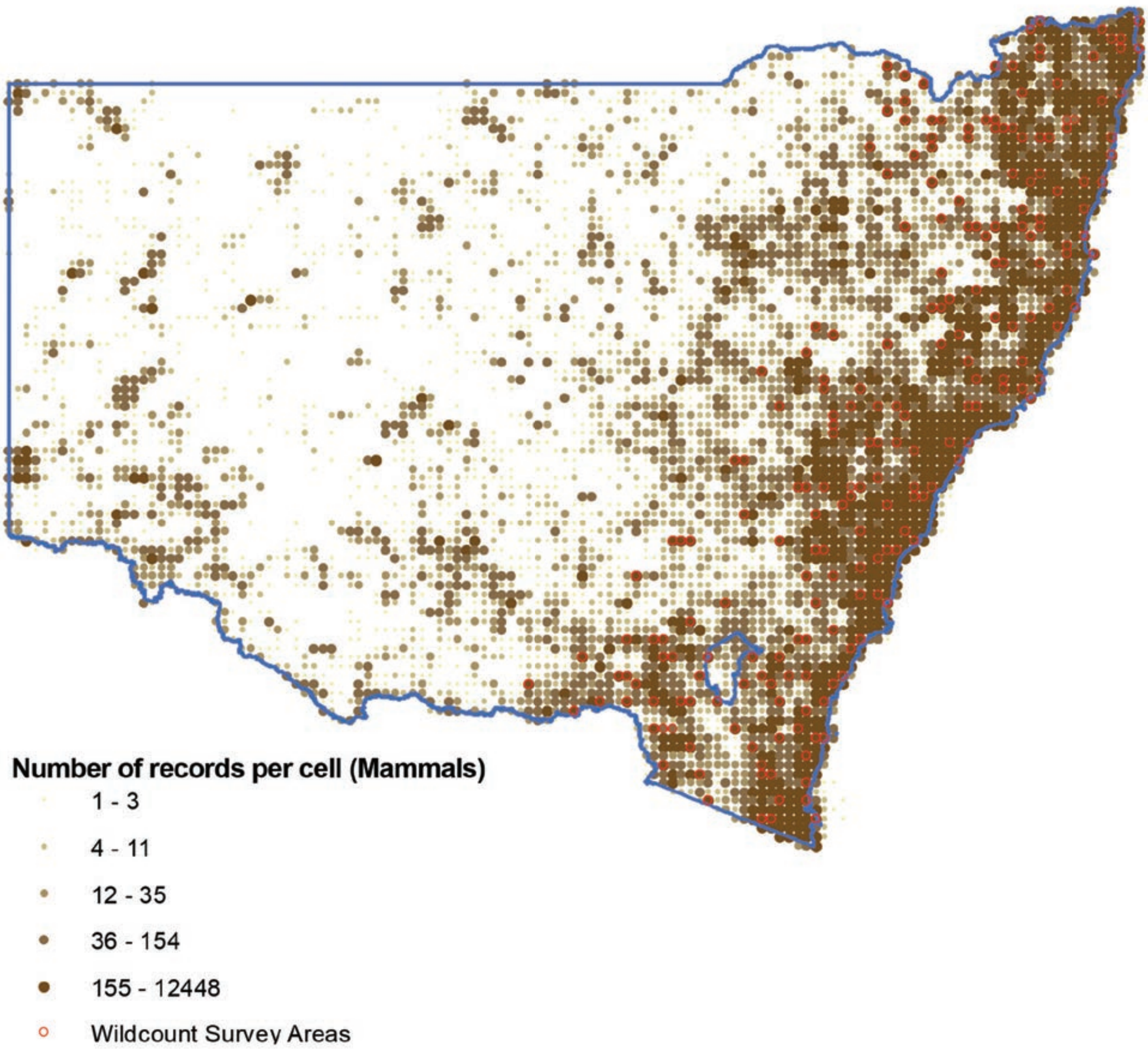

Figure 17. Mammal record density map for the NSW Wildlife Atlas. Grid size is 0.1 degrees. Classification was performed using 5 quantiles. Cells encircled in red indicate areas where Wildcount survey were performed.

Reserves, the graphs are separate prior to 1967. Five graphs are presented, showing growth of both National Parks and Nature Reserves and total area. A primary point of showing these graphically against the time of dedication is that the rate of accumulation of protected areas per year can be seen in its historical context. The simplest examples are the point of origin with the dedication of the first part of Royal National Park in 1879, then the passage of the first *National Parks and Wildlife Act 1967*, which was replaced by the *National Parks and Wildlife Act 1974* (NSW), which remains current.

The feature that emerges from the graphical display in the growth of the area of both National Parks and Nature Reserves is the length of the graph for National Parks, starting in 1879, and Nature Reserves since the passage of the *Fauna Protection Act 1948*. Details of the dates of dedication and increments in the areas of parks and reserves are given in Lunney (2014). The graphs here are updated to reflect two more years of growth until mid–2015 (30 June each year is a traditional tally time for the area of parks and reserves for the formal Annual Report of the Office of Environment and Heritage NSW – an important statutory document that is available on the web[15]).

The standout feature from all these graphs is the upward inflection point in the graphs in the late 1960s and the undiminished rise in the area of parks and reserves ever since. There are some flat points, and these in part reflect changing political emphases, and the time (in years) from first investigation of an area to its dedication as a park or reserve, but looking at a five year average, the rise is more even. In the last half century, there has been a 10–fold increase in the area of parks and reserves, which is breathtaking for those who were arguing the case for National Parks and Nature Reserves in the 1960s and

15 E.g. https://www.opengov.nsw.gov.au/download/15692 for Annual Report 2015–16 Office of Environment and Heritage.

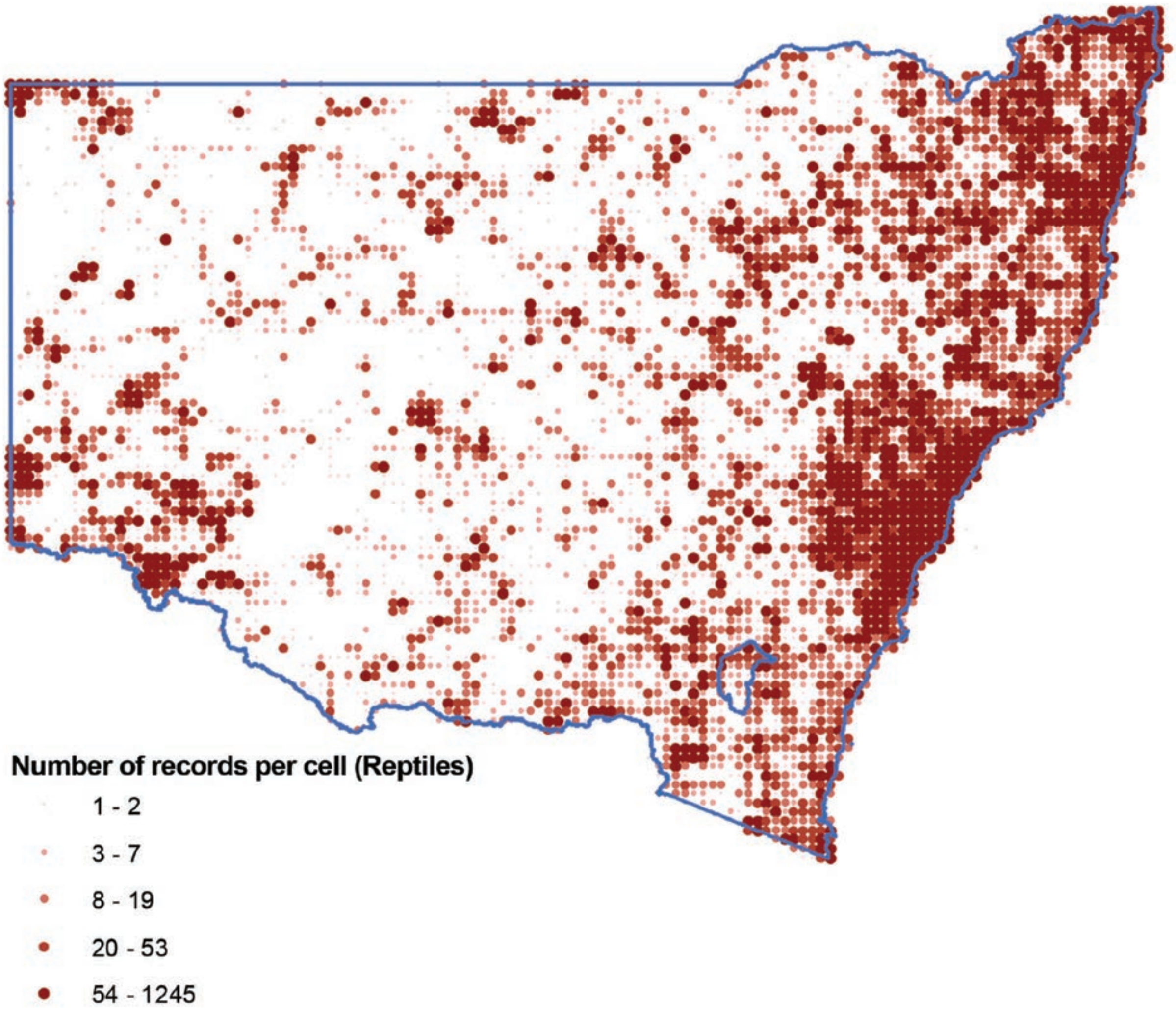

Figure 18. Reptile record density map for the NSW Wildlife Atlas. Grid size is 0.1 degrees. Classification was performed using 5 quantiles.

1970s, but this area is only half of the 17 per cent of the area of NSW required if the Aichi target 11[16] is to be met.

Rates of accumulation of fauna records

The fauna of NSW considered here are mammals, birds, amphibians and reptiles. Invertebrates were first considered when listed as threatened species following the passage of the *Threatened Species Conservation Act 1995*. Invertebrates also form part of the Atlas records when they were collected within parks and reserves. However, for these analyses, birds and mammals have records for the longest period, these having been recognised as fauna during most of the 20th century, with reptiles being included as fauna since 1974 with the passage of the *National Parks and Wildlife Act 1974* and all amphibians since 1992 following the passage of the *Endangered Fauna (Interim Protection) Act 1991* (NSW). (A longer description of these changes is given in Lunney 2017b, including the fact that 12 amphibians were listed as 'fauna of special concern' following amendments in 1983 to the *National Parks and Wildlife Act 1974*). The graphs reflect these changes in the legal meaning of 'fauna'. The records analysed are those up to 2015.

There are four elements to this analysis in two tiers. The first tier is the number of species (Figures 26–35), the other is the number of records (Figures 36–43). Each tier comprises two parts: a) the number of species in all tenures, *i.e.* in all of NSW (Figures 26–30), and the number of records in all tenures (Figures 36–39); and b) the number of species in parks and reserves (Figures 31–35) and the number of records in parks and reserves (Figures 40–43). The graphical representations are of all four sets of data. These data are compared with the rate of accumulation of the area of National Parks and Nature Reserves. The point of this exercise was to look at such issues as the adequacy of the data for analyses, when might be the best time to undertake such analyses, and what the results would have been if undertaken in different years. In short, it is to place contemporary concerns for inadequate data in an historical context.

16 Target 11: By 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas are conserved through ecologically representative and well–connected systems of protected areas and integrated into the wider landscape and seascape. https://www.cbd.int/sp/targets/rationale/target–11/

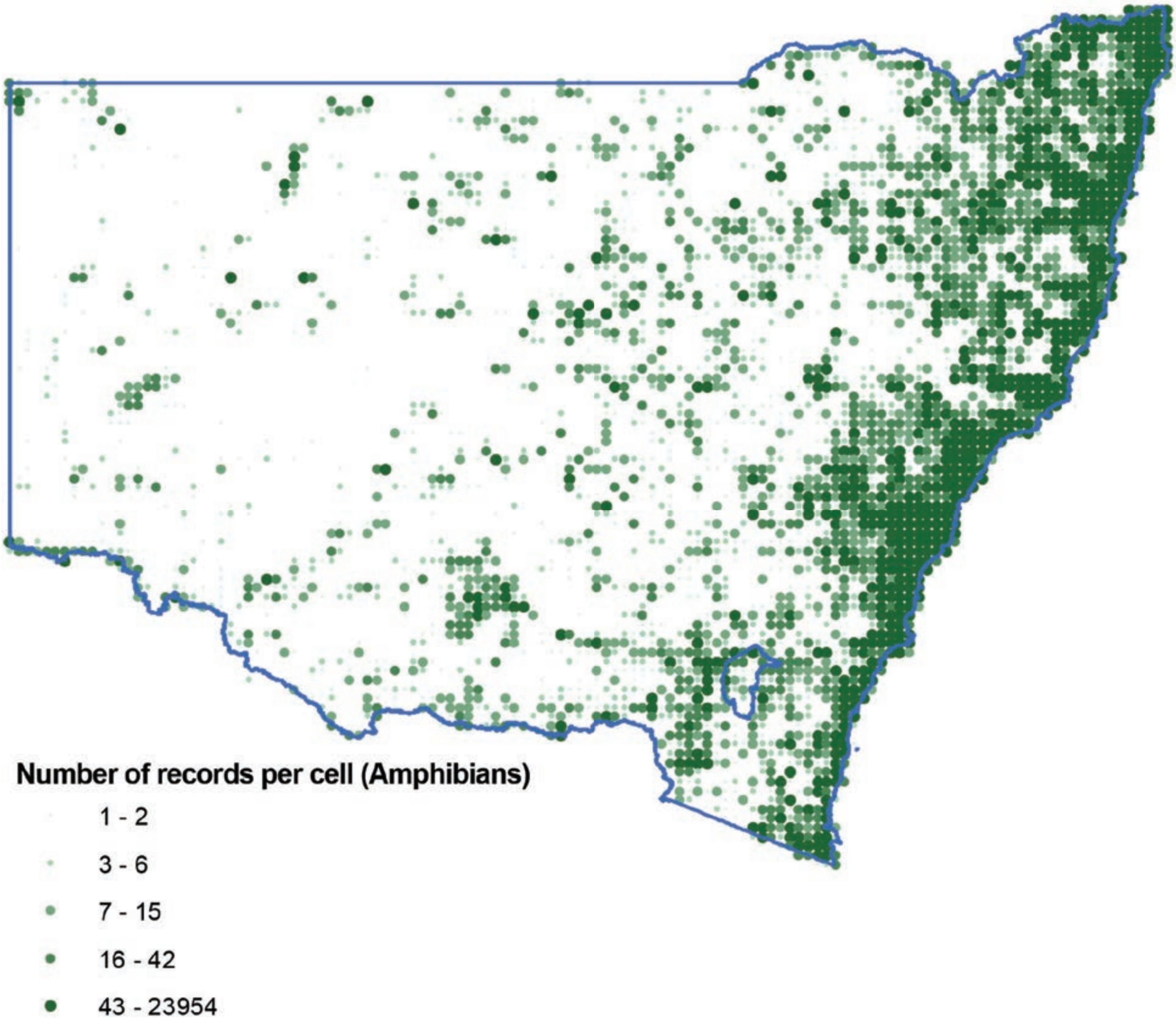

Figure 19. Amphibian record density map for the NSW Wildlife Atlas. Grid size is 0.1 degrees. Classification was performed using 5 quantiles.

These graphs show that the number of species known to occur in NSW has increased since the formation of the NSW National Parks and Wildlife Service in 1967 (Figures 26–30 and 36–39) although before 1967 many of the currently recognised species were known to occur in NSW. These earlier records largely reflect the efforts of museum and fauna collectors, as evidenced by the number of species recorded at 1967. It is also noted that these collectors initially focused on mammals and birds. The counts are lower in parks and reserves compared with the State as a whole, but the gap is not considerable as most birds (88% of species) were recorded at least once on National Parks and Nature Reserves, with mammals (86%), reptiles (88%) and frogs (95%) all having been recorded on a park or reserve at least once. The logic of the graphs points to the need to expand the extent of protected areas, and to capture all the habitats missed, unsurveyed or under–represented to date. We note, however, that a single record in a National Park or Nature Reserve does not equate to protecting a species, in particular as historical records are included in this analysis, and more detailed analyses of available data are required to fully understand the level of protection currently afforded to all species. These graphs indicate that land managers and governments had a good knowledge of the State's fauna assets when the National Parks and Wildlife Service was formed in 1967. However, it is worth noting that a complete list of the State's fauna was not compiled until 1992, when the first NSW Scientific Committee formed, so this information would have previously been difficult to access or compile (Lunney *et al.* 1996, 2000; Lunney 2017b). When the National Parks and Wildlife Service was formed in 1967, the distribution, habitat requirements and ecology of species found within NSW was poorly understood. This understanding increased as the number of records accumulated, and as a result of research published on the State's fauna. By comparison, when looking at the rate of accumulation of entities (Figures 9–15) their number continues to increase more than the rate of accumulation of species. This reflects the more recent (after about 1990) use of sub–species, as well as other taxonomic advances that have led to a more complex list of species in the state.

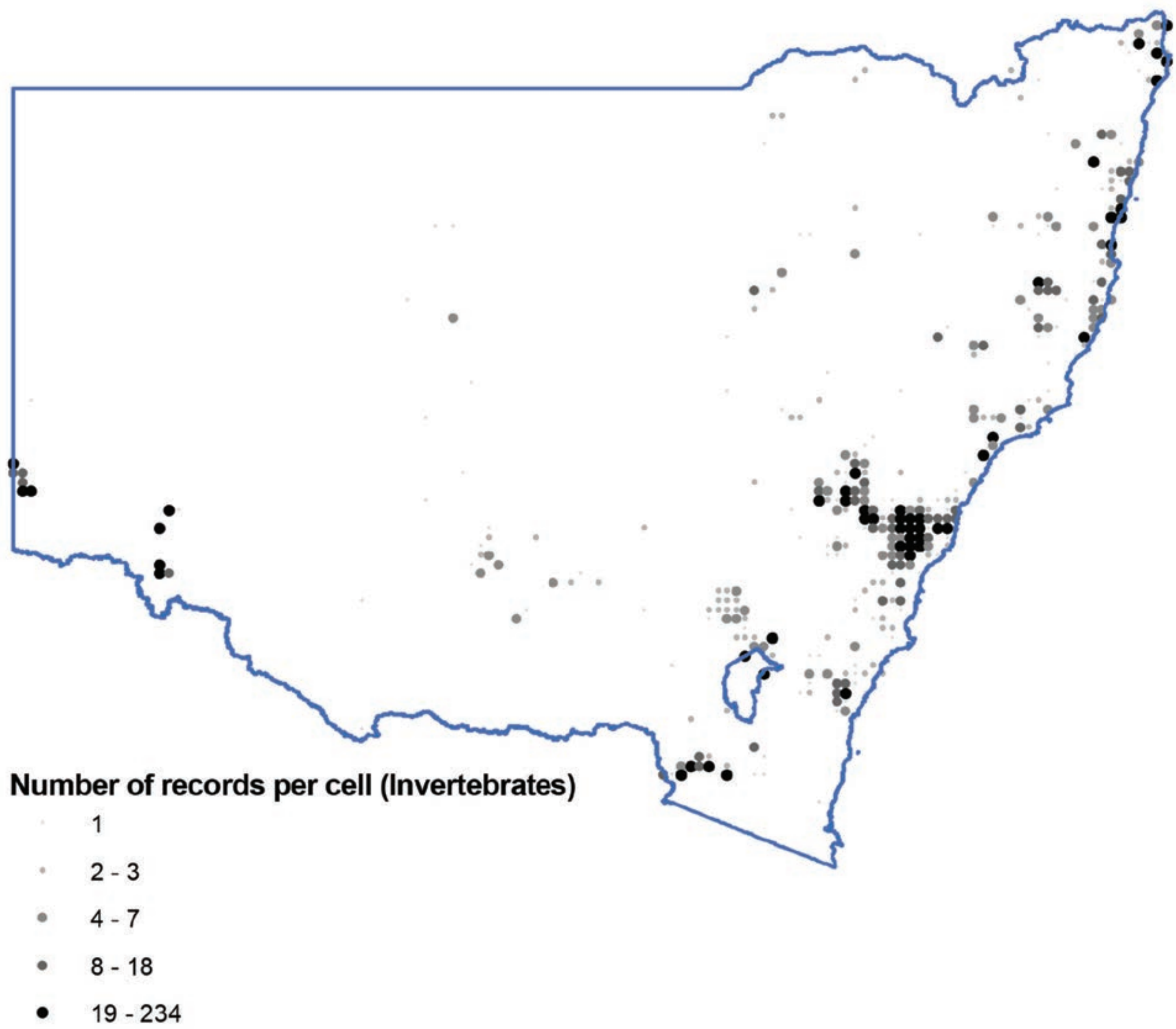

Figure 20. Invertebrate record density map for the NSW Wildlife Atlas. Grid size is 0.1 degrees. Classification was performed using 5 quantiles.

Discussion

What we have gleaned from the overview of species (and related groupings), by status, by protected area in NSW

This is the first numerical overview of taxa (i.e. species and related groupings), by status, by protected area/non–protected area in NSW. It reflects a very considerable effort by a great many people over many decades to achieve such a high level of protection of both species and areas. (The case for recording and publishing a history of these endeavours is growing, before too many more of the primary players are lost and their views and knowledge are no longer available.) It also identifies deficiencies in that there is a level of uncertainty for many species and many parks and reserves as to whether they will fulfil the function that one would hope that they would serve, namely to conserve all the fauna of NSW in perpetuity. This deficiency can be attributed to three features: 1) information, *i.e.* species data and location, that has been acquired but not lodged into the Atlas record system; 2) a record system that was not set up for the sorts of analyses that we have attempted here, but one that could be adapted to address such questions, and 3) the focus on some groups of animals, and some locations, gives a strong sense of unevenness in both the species focus and area.

What we can say at this point is, from an almost data–free start in 1967 when the NSW *National Parks and Wildlife Act 1967* passed through parliament, before computers and GIS, before systematic surveys of fauna or the preparation of threatened species lists or an Atlas scheme, that in nearly half a century the system of parks and reserves, and the record system that goes with it, represents major progress. The converse side of the examination of the data sets reveals large areas of NSW with little information and only a modest set of protected areas. We are also aware that the species–by–species studies, in relation to ecological assessments of their long–term viability in the current set of parks and reserves, are yet to be undertaken. This will be much more than an extended analysis of the existing data, but we have shown that we can begin to make such assessments. One of the intentions of this study was to spur other scholars into more refined analyses, such as for

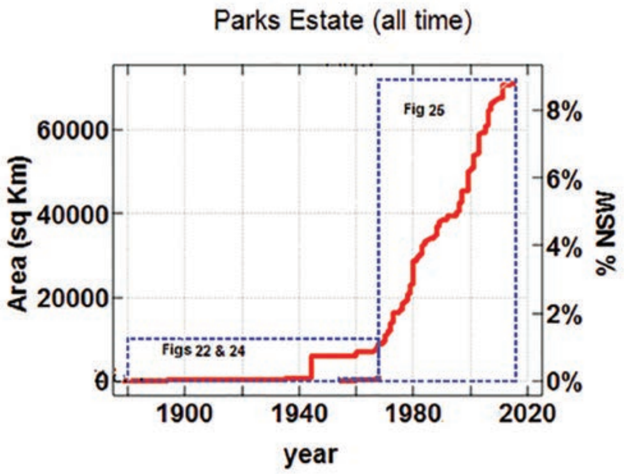

Figure 21. Growth in area of the National Parks and Nature Reserves in NSW 1879– 2015 (30 June)

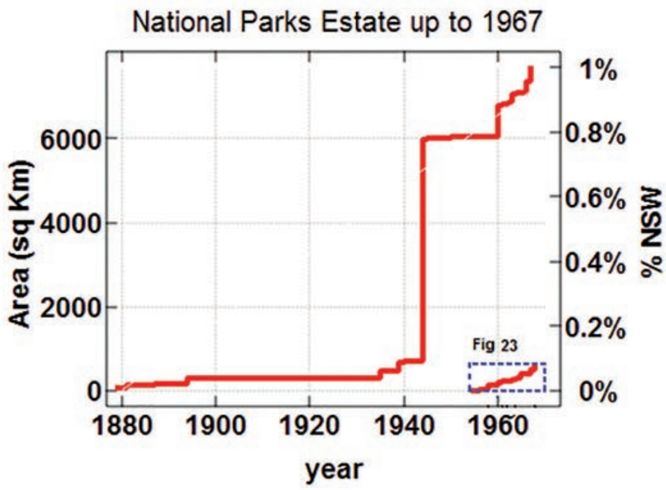

Figure 22. Growth in area of National Parks and Nature Reserves in NSW prior to 1967.

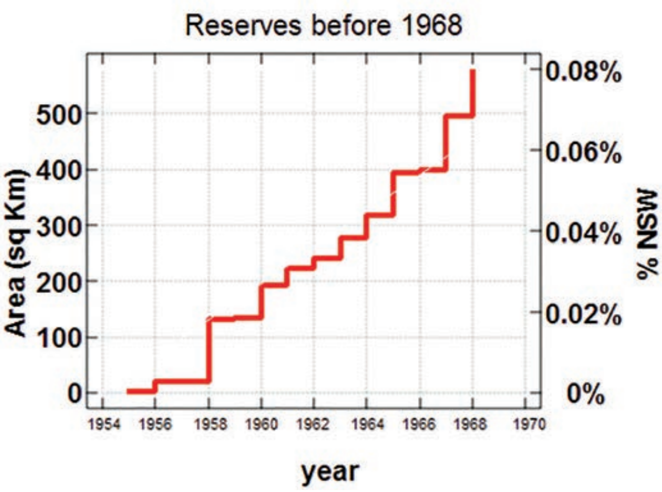

Figure 23. Growth in area of Nature Reserves in NSW between 1955 and 1968.

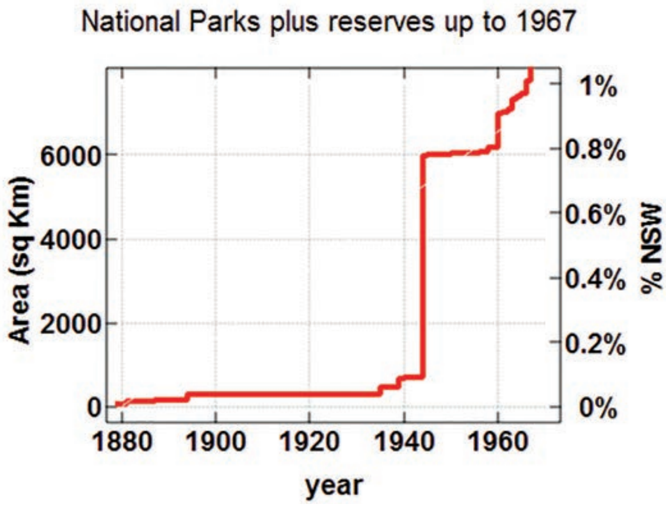

Figure 24. Growth in area of National Parks and Nature Reserves NSW prior to 1967.

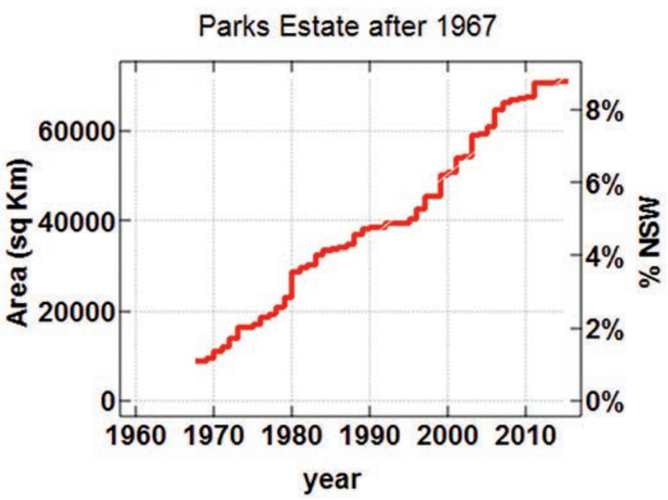

Figure 25. Growth in area of National Parks and Nature Reserves in NSW after 1967.

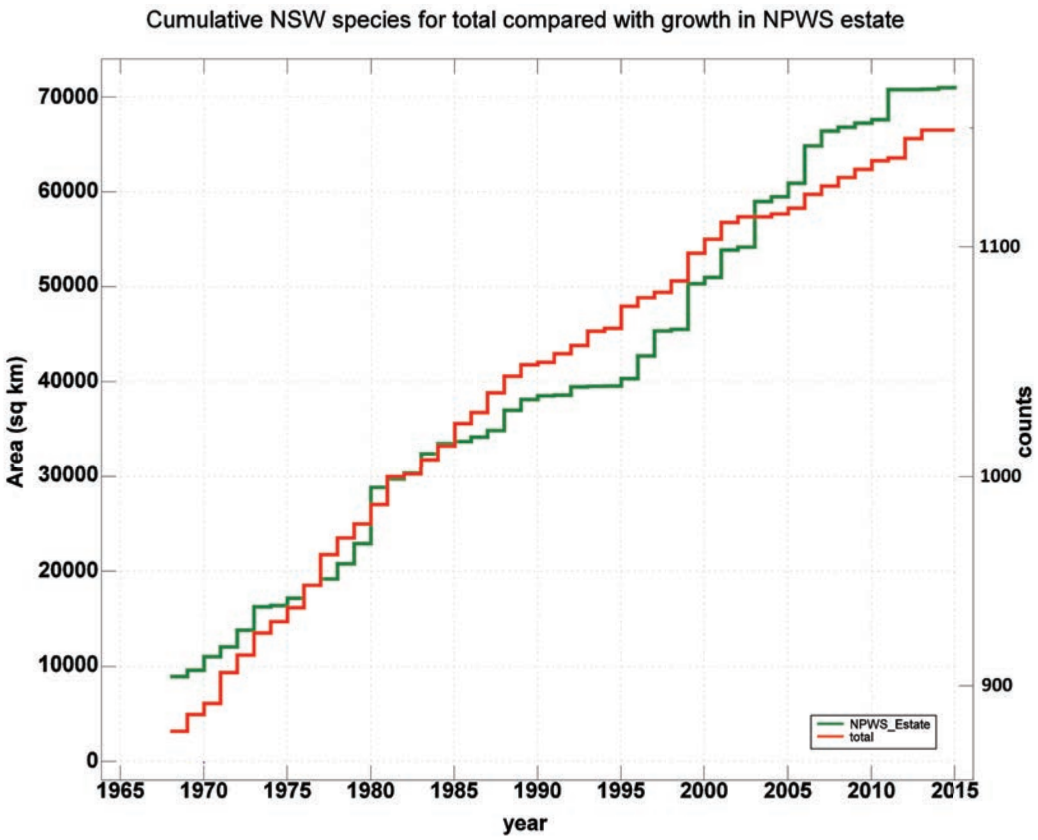

Figure 26. Cumulative count of all species (mammals, birds, frogs and reptiles) recorded in NSW in all tenures compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

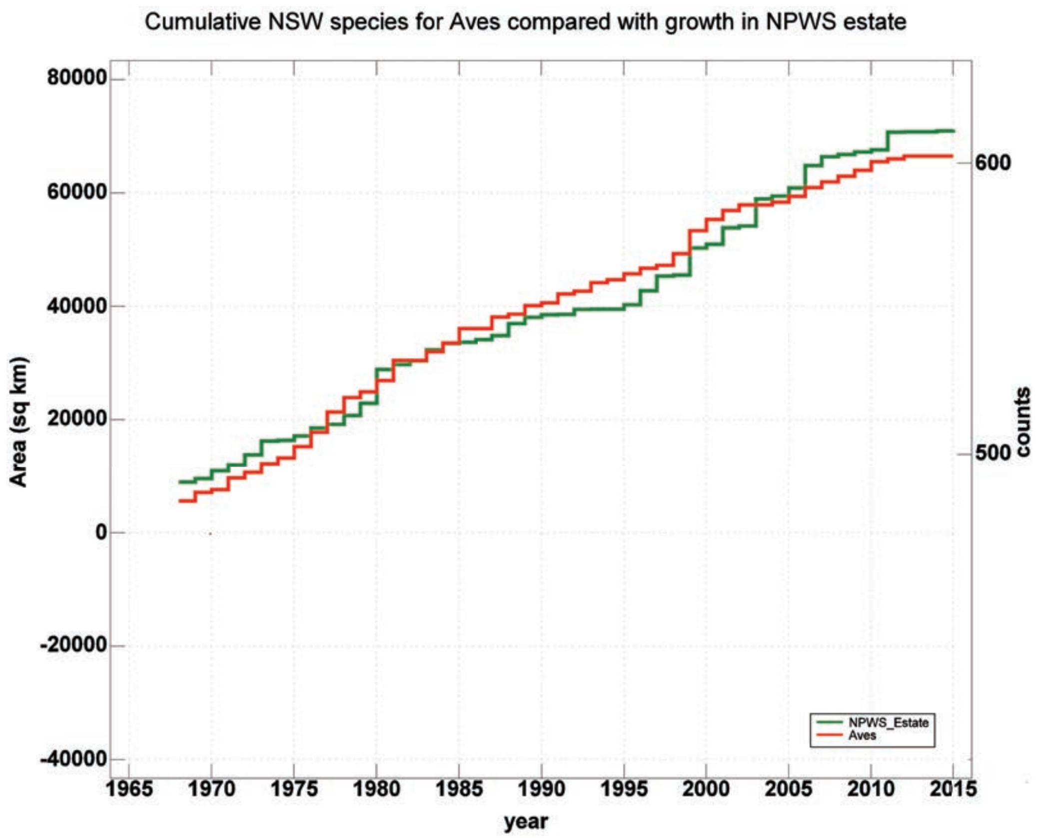

Figure 27. Cumulative count of all bird species recorded in NSW in all tenures compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

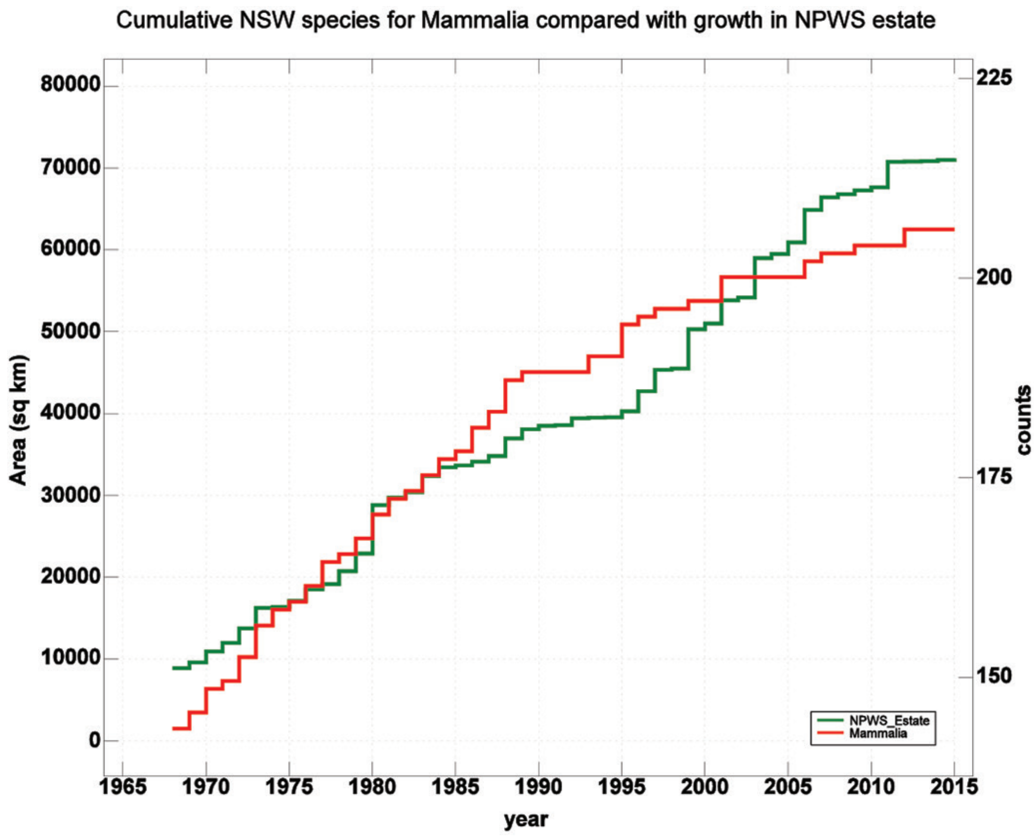

Figure 28. Cumulative count of all mammal species recorded in NSW in all tenures compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

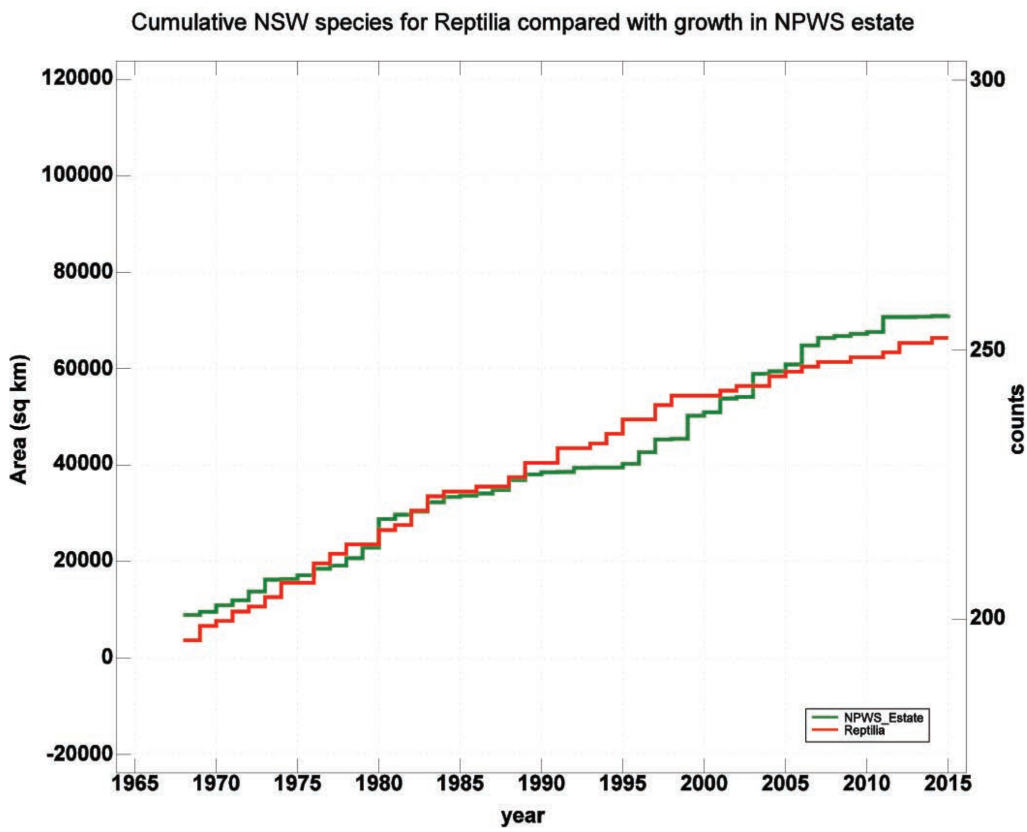

Figure 29. Cumulative count of all reptile species recorded in NSW in all tenures compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

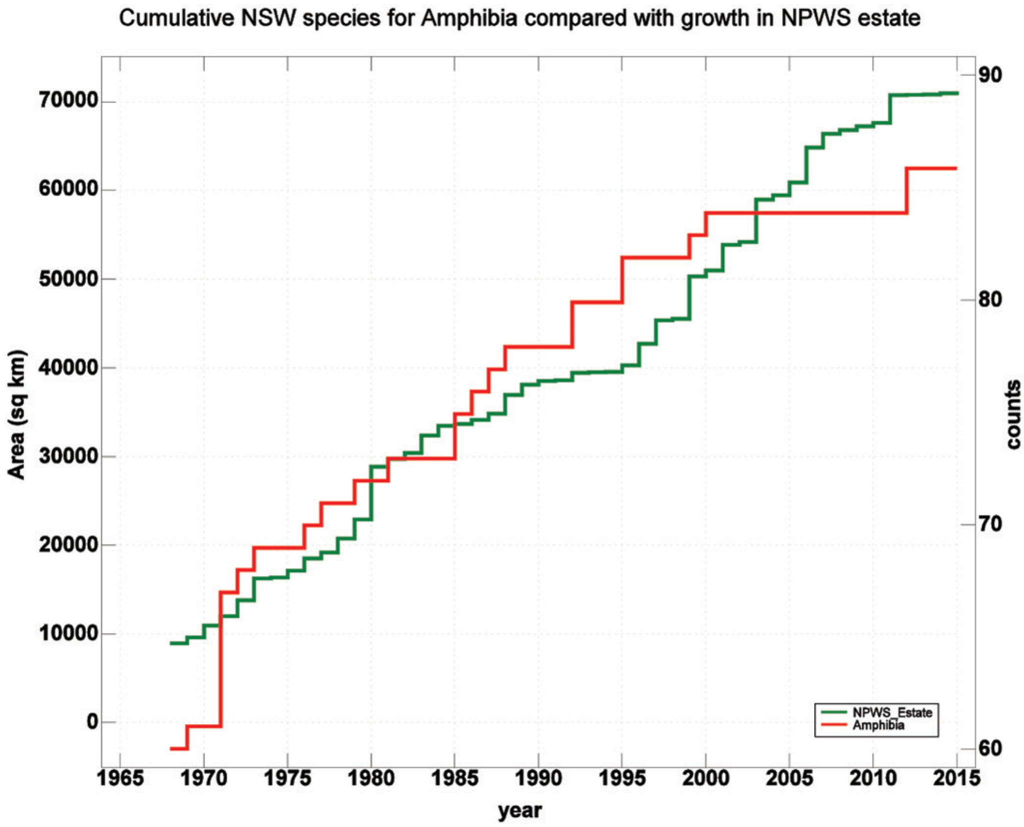

Figure 30. Cumulative count of all frog species recorded in NSW in all tenures compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

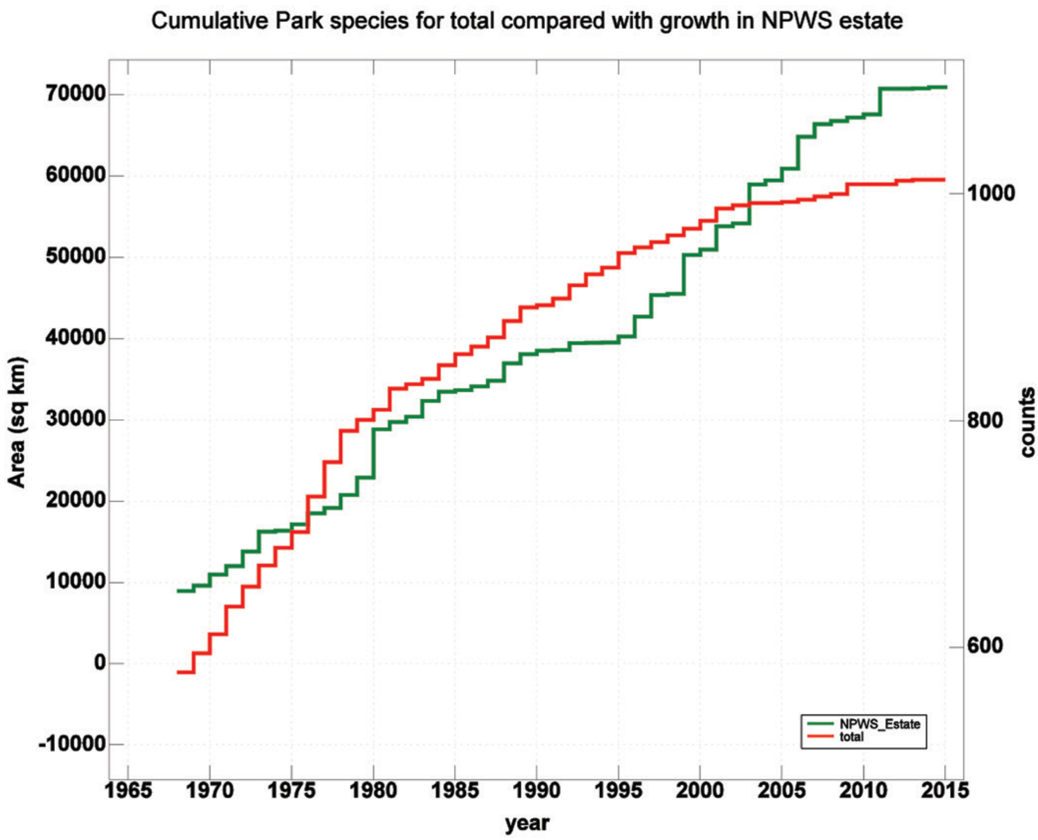

Figure 31. Cumulative count of all species recorded in NSW within in parks and reserves compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

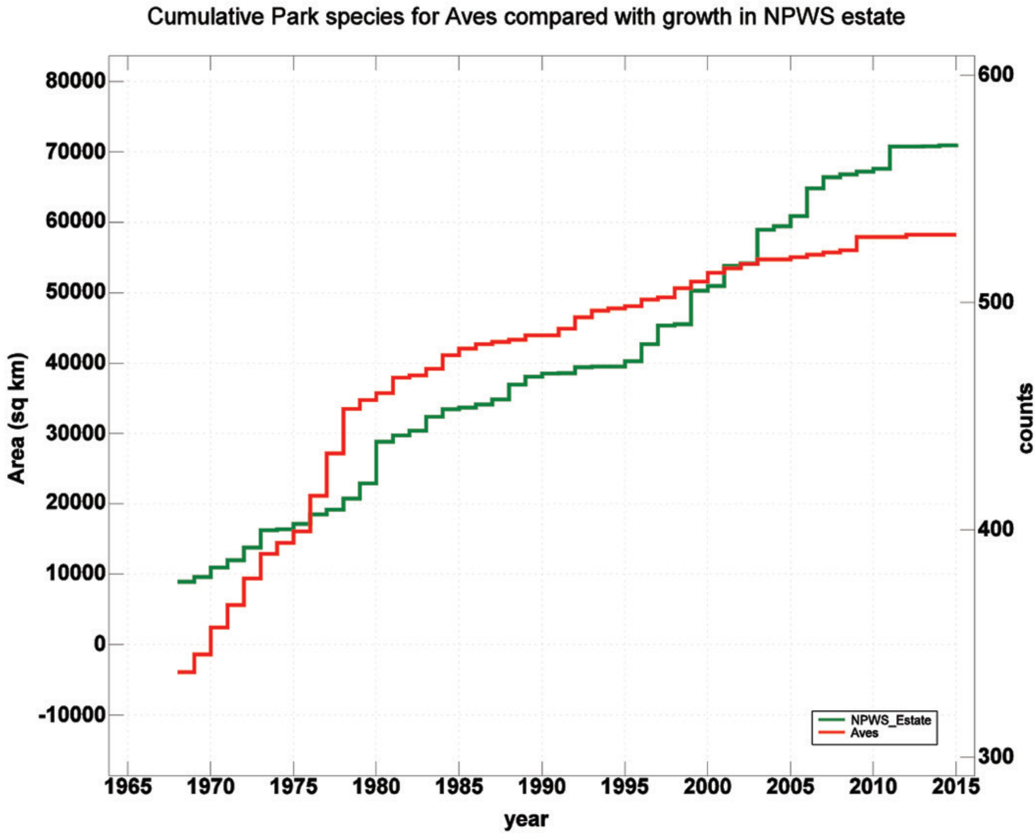

Figure 32. Cumulative count of all bird species recorded in NSW within in parks and reserves compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

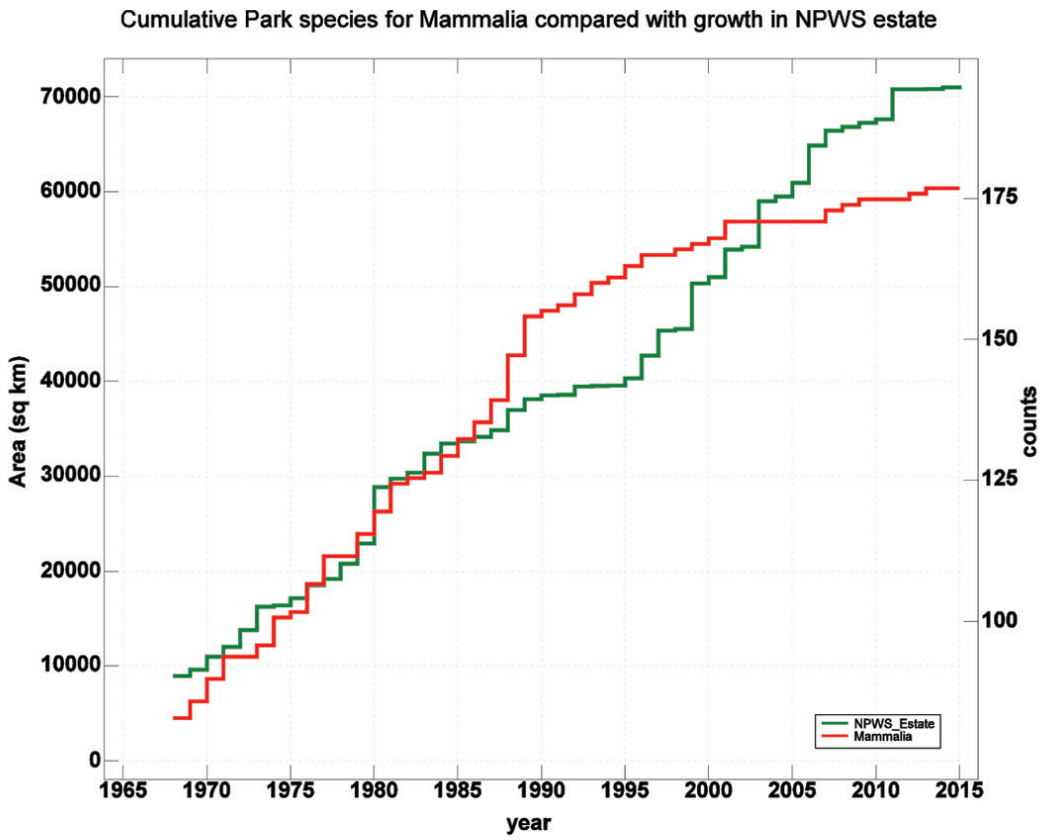

Figure 33. Cumulative count of all mammal species recorded in NSW within in parks and reserves compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

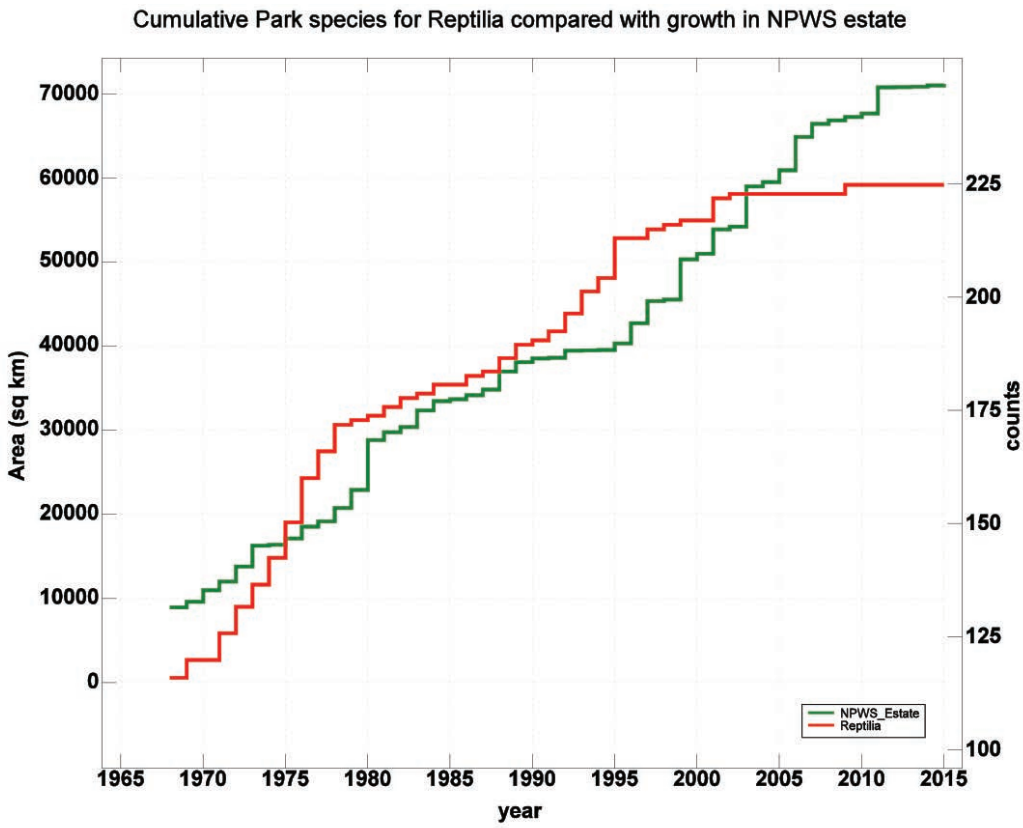

Figure 34. Cumulative count of all reptile species recorded in NSW within in parks and reserves compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

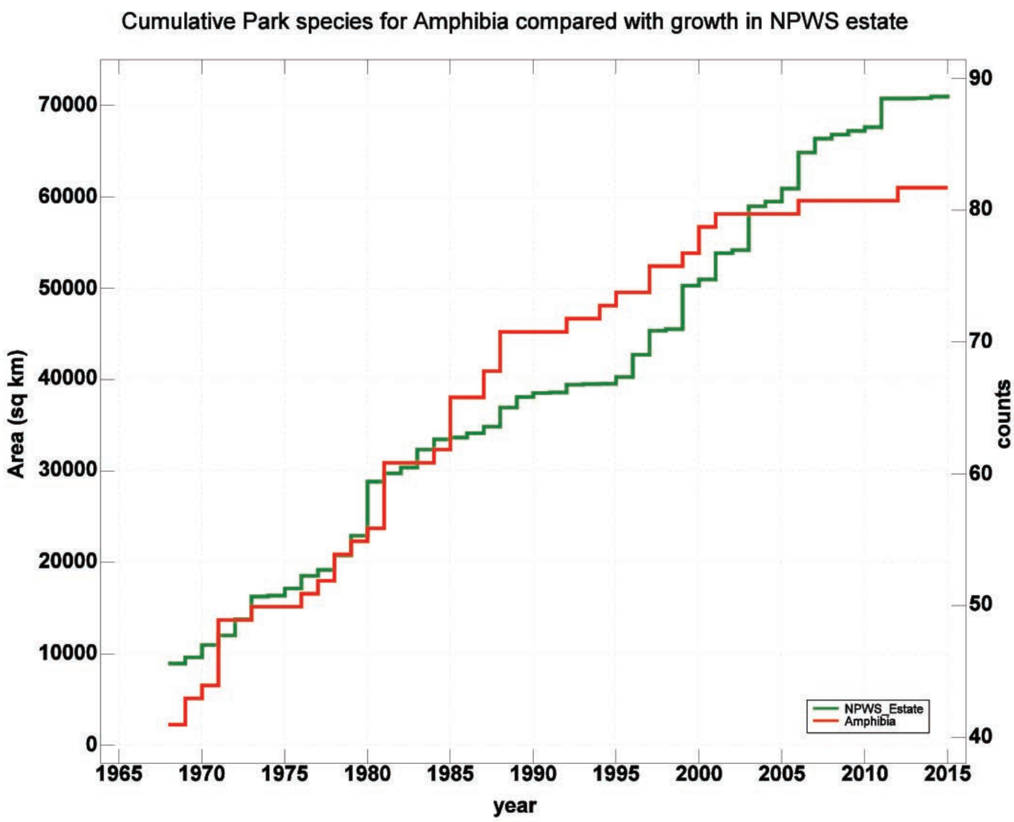

Figure 35. Cumulative count of all frog species recorded in NSW within in parks and reserves compared with the growth in areas of the national park system (in km^2) from 1967. In this graph only conventionally accepted binomial species were used as opposed to entities, used earlier in this paper.

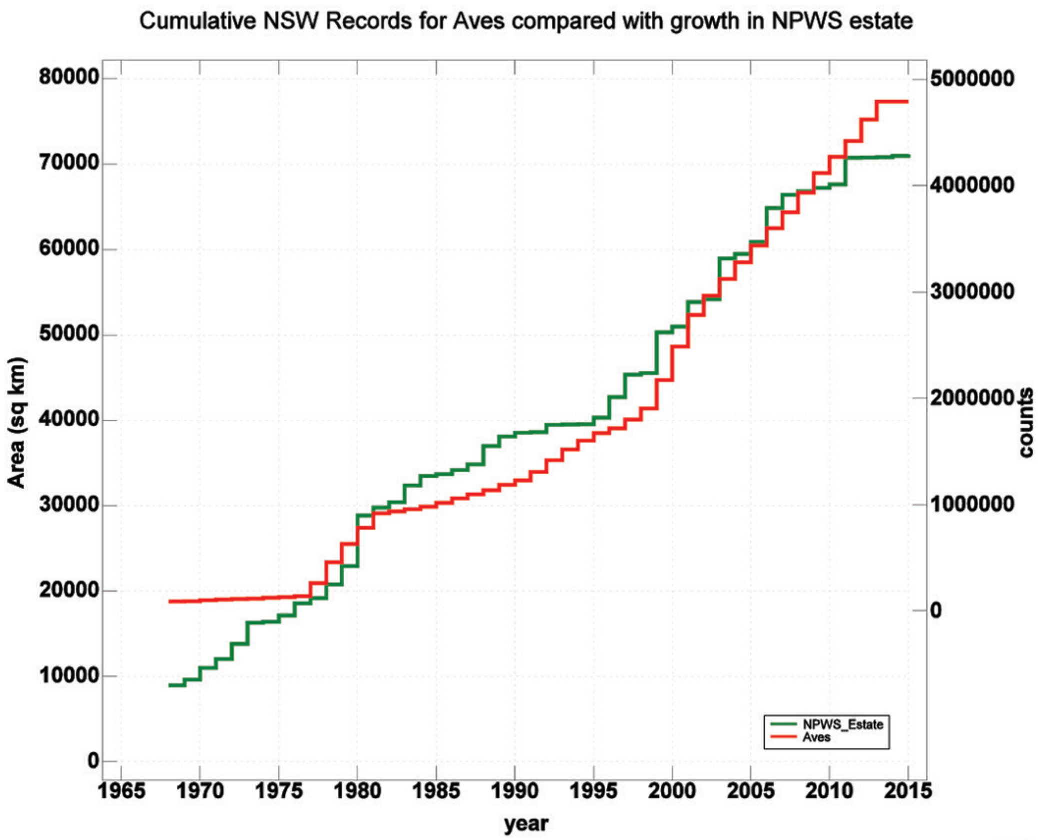

Figure 36. Cumulative count of all the records of birds recorded in NSW in all tenures compared with the growth in areas of the national park system (in km^2) from 1967.

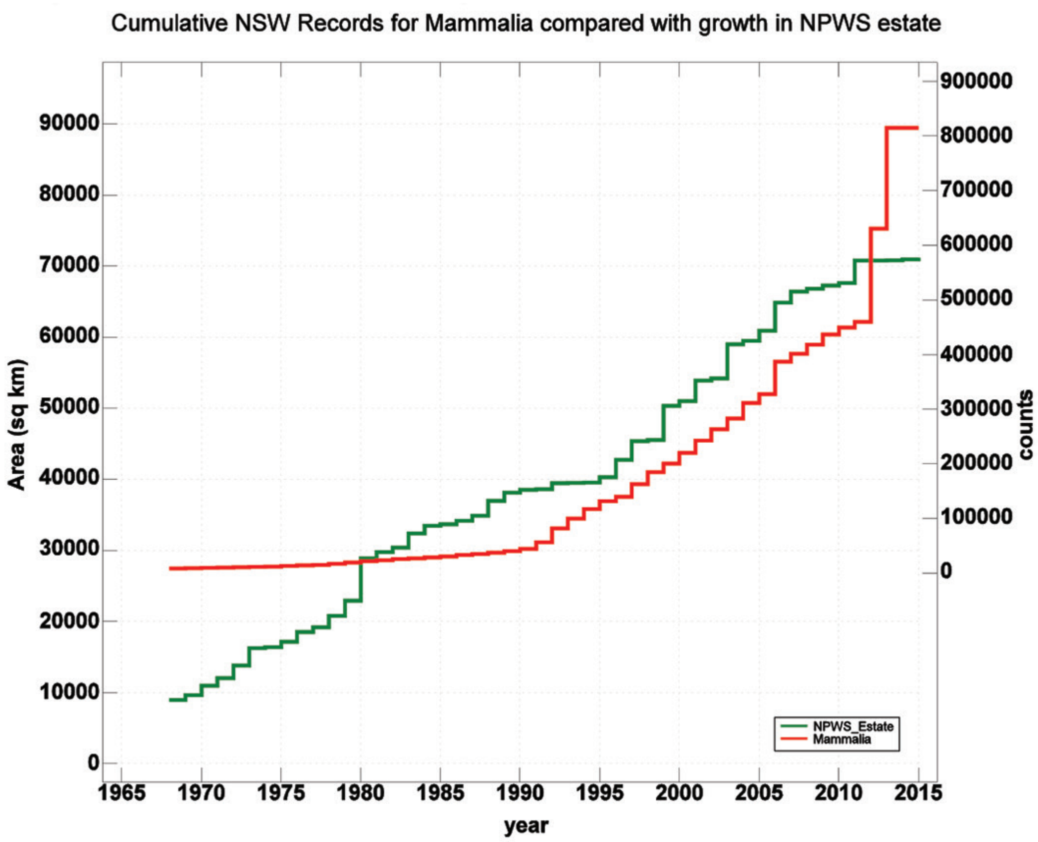

Figure 37. Cumulative count of all the records of mammals recorded in NSW in all tenures compared with the growth in areas of the national park system (in km^2) from 1967.

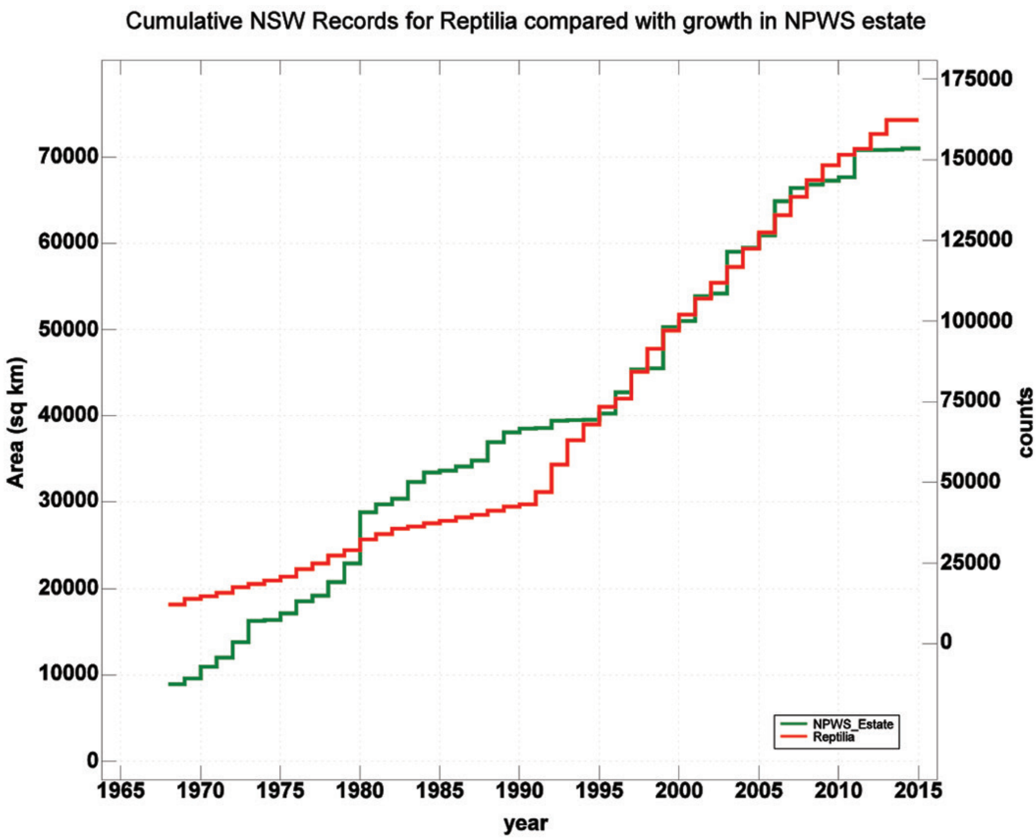

Figure 38. Cumulative count of all the records of reptiles recorded in NSW in all tenures compared with the growth in areas of the national park system (in km^2) from 1967.

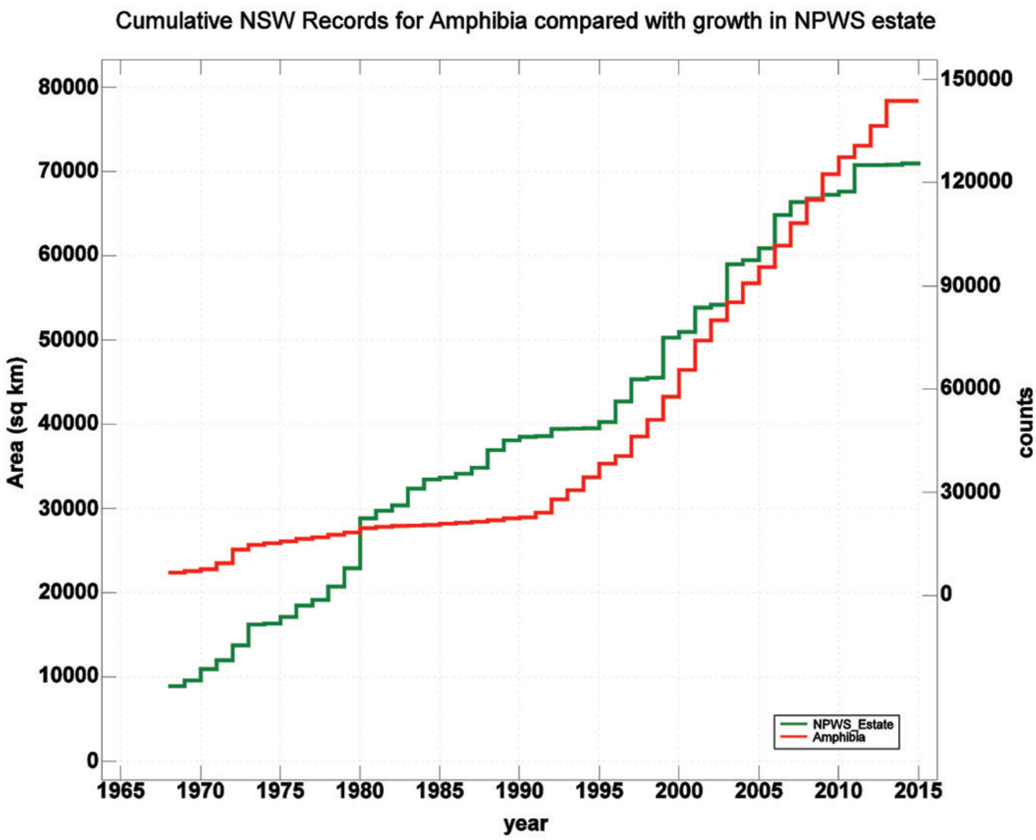

Figure 39. Cumulative count of all the records of frogs recorded in NSW in all tenures compared with the growth in areas of the national park system (in km^2) from 1967.

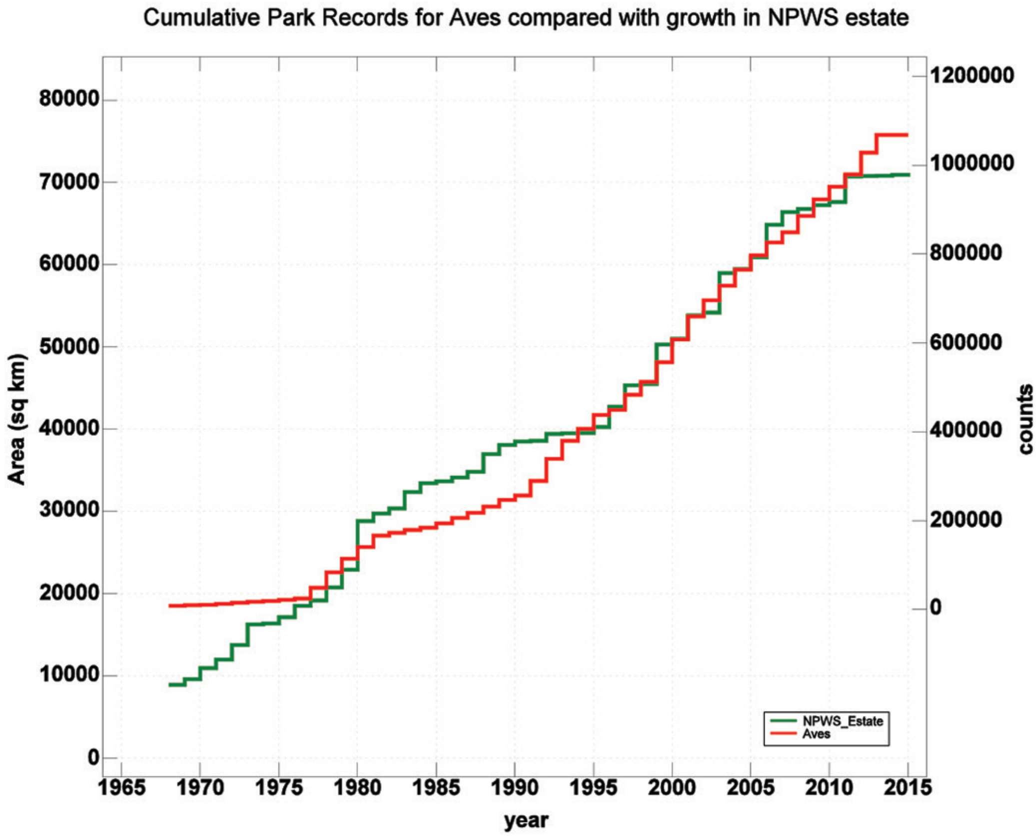

Figure 40. Cumulative count of all the records of birds recorded in NSW within parks and reserves compared with the growth in areas of the national park system (in km^2) from 1967.

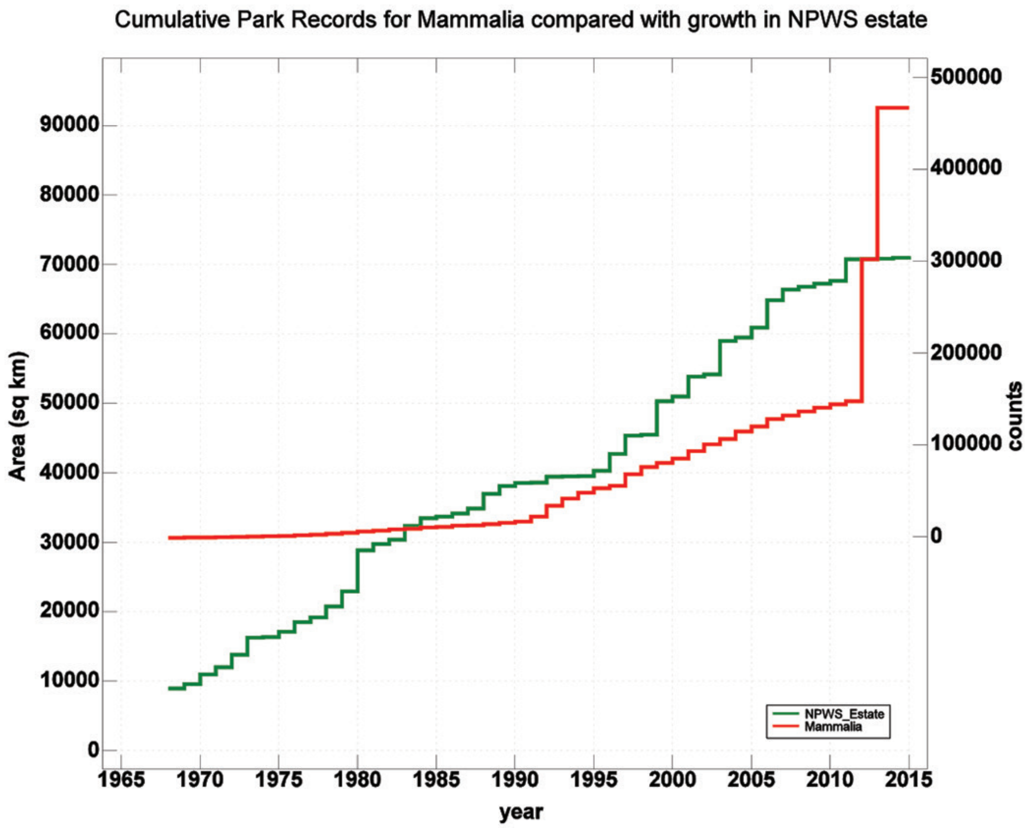

Figure 41. Cumulative count of all the records of mammals recorded in NSW within parks and reserves compared with the growth in areas of the national park system (in km^2) from 1967.

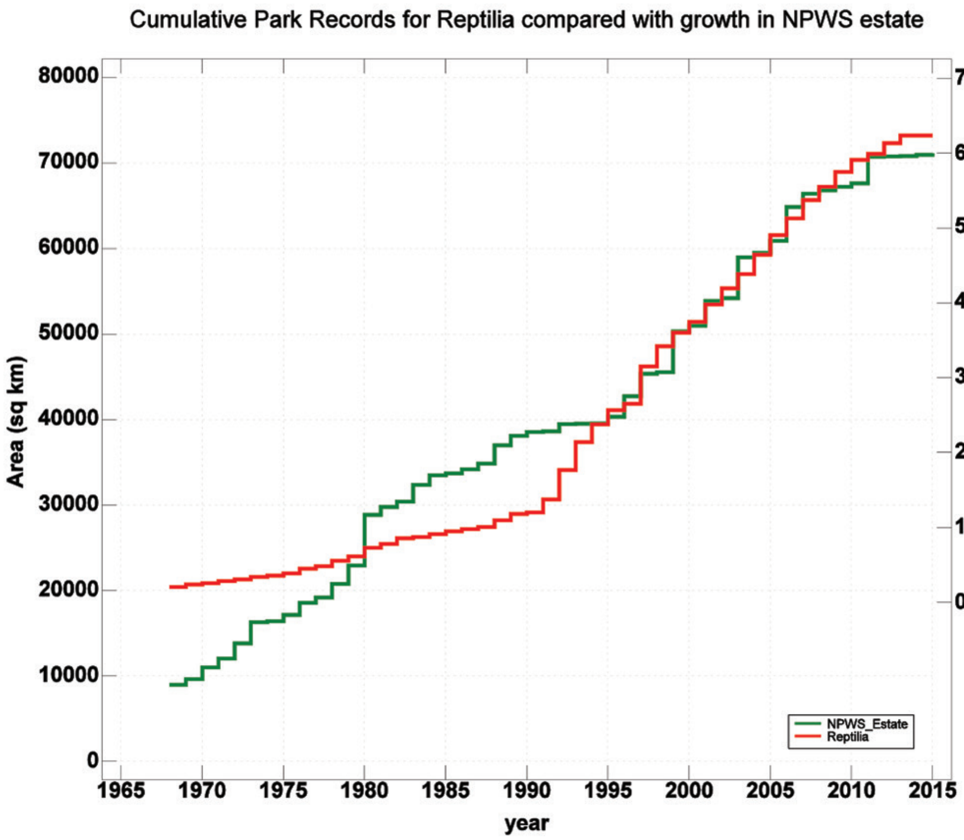

Figure 42. Cumulative count of all the records of reptiles recorded in NSW within parks and reserves compared with the growth in areas of the national park system (in km^2) from 1967.

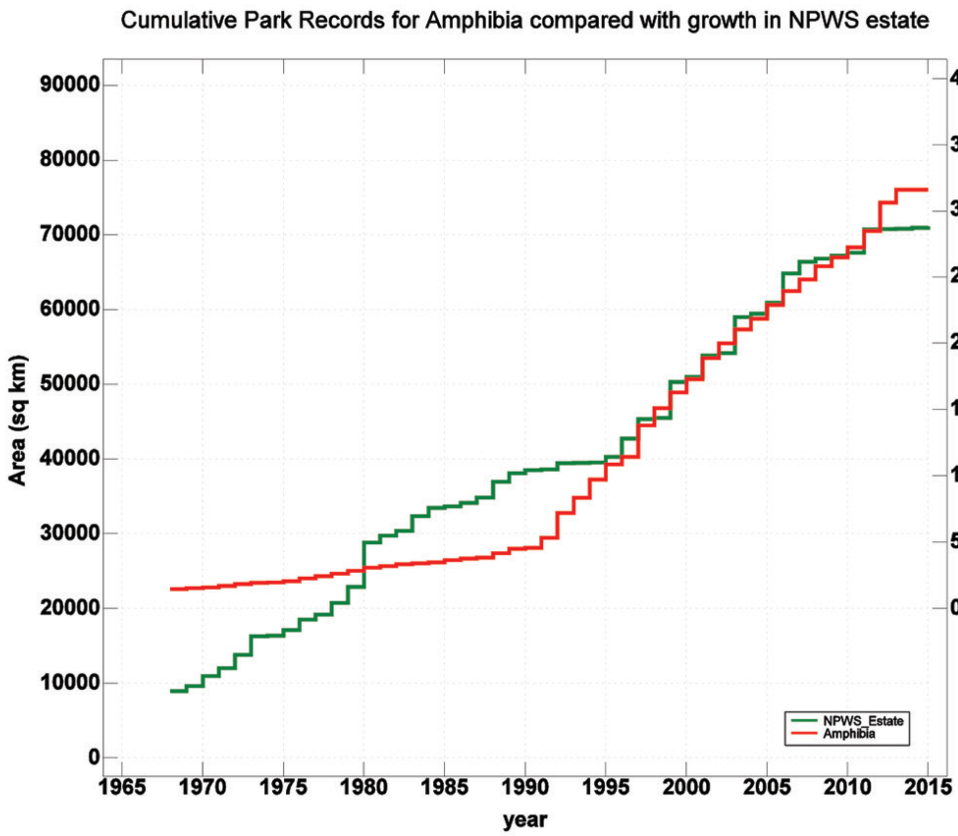

Figure 43. Cumulative count of all the records of frogs recorded in NSW within parks and reserves compared with the growth in areas of the national park system (in km^2) from 1967.

species or reserve type, bioregion and per threat, such as distribution of cats or foxes, as well as fire history, roading, logging, land clearing, stocking rates of sheep and cattle, and climate change. All these factors, among others, will matter in the preparation of any final judgment as to the capability and the value of the parks and reserve system in NSW for conserving the fauna of NSW. A more realistic aim would be to examine the extent to which the parks system contributes to a long–term vision of native fauna conservation, in conjunction with other land uses, such as forestry, farming or urban areas.

This study has also revealed that we have a very poor understanding of some faunal groups, in particular invertebrates, reptiles and amphibians. We are not the first to make these observations; for example Holwell and Andrew (2015) for invertebrates and Webb *et al.* (2015) for reptiles both note high diversity and low levels of knowledge for these groups. The limited information base we detected in semi–arid and arid landscapes is also noted by Webb *et al.* (2015) for reptiles and Hero *et al.* (2015) for amphibians.

Craigie *et al.* (2015) reviewed the protected area system in Australia and reported that 15% of Australia is reserved (9.0% of NSW) but there is a large variation across regions. Craigie *et al.* (2015) also reported that most large reserves are far from human population or productive lands (for NSW the proportion of land reserved is as follows: Major city 0.7%, Inner regional 21.8%, Outer regional 55.3%, Remote 7.8%, Very remote 14.4%) and that there has been recent growth in Indigenous Protected Areas and private conservation reserves.

Craigie *et al.* (2015) also stated that, "It is difficult to say how effective protected areas are due to shortcomings in monitoring and evaluation, but the data that exist show that the biodiversity outcomes are variable and that management effectiveness could be substantially improved", and later in their review: "Given the level of investment in protected areas it is critical that we understand the mechanisms underlying protected areas' effectiveness in retaining biological values". With respect to the biodiversity outcomes for protected areas for Australia, Craigie *et al.* (2015) conclude that the performance in maintaining populations of species remains poorly studied, and that long–term, systematic population monitoring is exceptionally rare, but critical in determining changes in natural values. We agree with both these views based on the patterns we have observed in the recording of information for most of NSW.

Researchers in parks and reserves

This study has demonstrated that the protected areas in NSW are extensively used by researchers and others keen on recording fauna, thereby demonstrating the value of the protected areas system for wildlife research. Lunney (1998) had put the case for the role of National Parks and Nature Reserves as a field for science, and pointed out that we need parks and reserves because they retain the opportunity to study natural processes beyond human lifetimes. Parks and reserves are the best places for long–term studies of natural environments and populations of animals and plants not affected by development and other human impacts. Lunney (1998) also considered that many scientists had yet to recognise the worth of parks and reserves. On that point, Lunney (1998) noted that the *1996 State of the Environment* (Commonwealth of Australia 1996) did not make a single mention of National Parks, although it did mention reserves, but only to decry their lack of representativeness. We do need to ensure that research is strongly encouraged in National Parks and Nature Reserves, and in wilderness areas, and not limit research only to those studies that have immediate benefit to local managers. The Wildlife Licences are a primary source of information about which species and which areas are being researched and to what extent protected areas or areas with potential for protection are or have been the subject of specific survey or research. A limitation is that these are not publicly available, but that would be a matter of filtering the information to provide the data sets without compromising individual privacy. However, fauna records from Scientific Licences are required to be lodged with the Atlas, so the data are available. We note that this does not include invertebrates (see Tables 1, 2, 3 and 4).

Examination of the NSW Wildlife Atlas

The tabular information on protected area by animal group has demonstrated that, while a wide range of parks and reserves do have records, the records are strongly concentrated along the coast and ranges of eastern NSW. The question of whether the protected areas system will conserve the native fauna of NSW would, in our view, require a detailed species by species investigation, which is not possible from these databases. It needs the published results of species–specific, scientific studies. Nevertheless, the data we have presented allow the view to be formed that while the parks and reserves system has limitations it contains at least one record of about 90% of the mammal, bird, reptile and frog species in NSW. A single record of a species on a reserve does not indicate that a species could be considered protected. Multiple locations, habitat connectivity and the impact of threats need to be considered to make this judgment. More species may well be inside the system of parks and reserves but not recorded as present in the Atlas, others may have become extinct, but as historical records are included in this analysis, they remain in the species counts. The case for extended survey and research is made stronger by this analysis and by the realisation that crucial development decisions are being made on the basis of too little recorded information. The maps allow the conclusion to be drawn that there are many areas where we have only modest information on the presence and distribution of our native fauna, both inside and outside the reserves system. Most threatened species had records in a protected area. An optimal reserve

system would capture all our fauna, particularly threatened species, within multiple reserves for each species in case catastrophic events such as fire, or creeping decline from climate change, invasive species or urbanisation, eliminated a species from any one protected area.

The number of parks or reserves where a species has been recorded is one measure of its security. A species with a large geographic distribution with numerous populations in a range of protected areas is likely to be less prone to extinction from chance events. We found that a few species are only recorded in one protected area, while others are found in many. Some species rely entirely on protected areas and these species tend to be habitat specialists (*e.g.* alpine species).

In terms of tenure, the highest number of records is off park (n = 4,406,286). With regard to density, the greatest number of records per area is in Nature Reserves, at 40.6 records per km^2. Overall, across NSW, there are 7.6 records per km^2 for all animal categories. We note that the more than six million fauna records in NSW represent a major exercise in recording such a large volume of data. However, when we consider the records per square kilometre, there would be no chance of making a claim we have a clear understanding of the distribution of our fauna. The caution here is that, for many modelling exercises, or IUCN assessments (IUCN 2016), the Atlas records provide a useful tool, but they do not approach capturing the diversity of the fauna across the State. For example, if one were examining frogs by tenure, the number of records in wilderness (n = 3,678) would suggest that wilderness has little value for frogs. An alternative explanation – and one born from personal experience – is that it is more difficult to conduct detailed surveys in wilderness. By contrast, the new survey technique of camera trapping (WildCount) readily records some large mammals, such as swamp wallabies, in protected areas. In wilderness areas there is a total of 61,471 mammal records, 27% (n = 16,363) of these are swamp wallabies, and 94% (n = 15,422) of these records are from one source (WildCount). The records for invertebrates are very patchy, *e.g.* the salt marsh mosquito *Ochlerotatus* (*Aedes*) *vigilax*, a major coastal pest species for NSW (Russel 1996) and a common mosquito in the heavily populated and fauna–record–dense eastern coastline, has been recorded a mere four times in the Atlas. One could explore any species by tenure in detail and arrive at similar skews in the data. The most important immediate conclusion is not to assume that there has been a systematic state–wide survey for all species, but rather take into account the method used for data collection. The Atlas itself is a valuable repository of information gained so that people can use it for specific purposes, which may be a local area question or a state–wide overview. The data referred to come from Table 6b and Figure 5.

Two examples of this non–systematic input to the Atlas relate particularly to mammals. In 2006, a state–wide, community–based wildlife survey (Lunney *et al.* 2009) concentrated on 'charismatic' mammals (Figure 6). Likewise, in 2012 and 2013, the high number of mammal records (Figure 5) reflects the signal from the new technique of camera trapping (WildCount). Given that both these projects were OEH, there was a high level of incentive to lodge the records in the Atlas, thereby further biasing the system, which is run by OEH. The biases also reflect another element of both the community–based survey and the camera trapping techniques. The community–based survey was a map–based survey sent to residents in NSW (Lunney *et al.* 2010). But since most people live in the eastern third of the state, most of the records are found in those areas where residents on private land recorded what they had seen, including in parks and reserves. The camera trapping conducted by OEH is a survey technique established to monitor populations of animals on parks and reserves and is limited to the eastern portion of the state. Each of these policy decisions and survey techniques compound biases in the distribution records of vertebrates on parks and reserves, and these two techniques highlight the necessity to recognise the survey technique used to record the fauna when drawing on Atlas records for a specific purpose. The opposite is also true, namely that an absence of records is not a statement that private land does not have the fauna, or the western part of the state not have the fauna, but primarily it reveals they have not been the subject of the same intensive effort for fauna survey as emerged from the maps in Figures 16–20.

The data could be also misconstrued to suggest that protected areas are breeding grounds for pest species, but the more likely explanation is that well known pest species on private land simply do not go into the Atlas record system. The way the data (see Table 7) are recorded does not allow us to distinguish between these vastly divergent suggestions. Once again, one needs to interrogate the Atlas system intelligently before claims, interpretations or modelling are undertaken.

An outsider might be tempted to conclude that almost all the native mammal fauna of NSW lives in a park or reserve or, more intelligently, that there was simply little survey on private land, or that most records from private land have never been recorded in the Atlas. This is the same reasoning that applies to pest/feral mammals, where the figure was 50.7% of all records. In short, there is an apparent heavy bias in the system if one were taking a tenure–blind approach to analysing the distribution of native and feral mammal fauna. While it is rewarding for the Atlas to have captured so much information from surveys within parks and reserves, it is correspondingly disappointing that private tenure and other Crown lands have either not been well surveyed or the surveys have not been logged into the Atlas (see Table 8). State Forests are also relatively record dense, and while we did not explore this in detail, it is a logical consequence of the legal requirement for pre–harvest surveys (see Slade and Law 2017). If the aim of the exercise was to track the decline of a species or group of species, or the success of a recovery

plan for threatened fauna, then the Atlas does not yet provide the basic information to undertake such analyses.

A further conclusion could be drawn that, if one were considering generating a biodiversity index based upon Atlas records alone, a skewed index would result, which would mask the bias in biodiversity in the Atlas system. While there are many benefits of the Atlas system, anyone drawing on it would enhance the reliability of their use of it by understanding the basis for the collection and reporting of data. In fact, it should be a required step in any analysis.

Rates of accumulation of protected areas, records and species

That the number of records and the number of species rises together identifies that the number of species is closely related to the number of records. This cannot continue because there is a finite number of species. The beginning of this event emerges from inspecting the records of mammals, which have risen sharply since 2012, reflecting the impact of WildCount, whereas the number of species shows that it is levelling off in about 2013, with 206 species in NSW (and 176 in reserves). The number of records of birds had a high start in 1967, reflecting a much longer interest in recording birds, and the possibility of doing so with low technology – binoculars, a field guide and a field note book. However the number of bird species is continuing to increase. Again, this cannot continue indefinitely. As birds are mobile species, the more recent additions to the list are often vagrant species, although shifting distributions of some species may continue to push new species into NSW (a subject worthy of study in its own right), which is a trend not seen in the less mobile frogs and reptiles. The number of bird species recorded in parks and reserves was, in 1967, initially a much smaller proportion (67% of the species known from the State), but this gap narrowed around 1978. At the State scale (Figure 27), the impact of the Birdlife Australia Atlas (both Atlas1 and 2) is not evident (the graph does not become steeper, however, this signal is seen within the National Parks estate, and at the bioregional and individual park scale where large increases in knowledge occurred during the first bird atlas (Figures 9, 10 and 15)). All the frogs (*i.e.* amphibia) first became recognised as fauna in NSW in 1992, and there has been little growth in the number of species in this group since then, indicating a lag between policy and the public and scientific interest in this group. In contrast, the rate of increase in frog species is more closely parallel to the growth in the area of parks and reserves. This points to a much longer term interest in frog species than the date of their official protection. Reptile records, and number of species, show an overall steady growth in parallel with the increase in the area of parks and reserves, with the growth in records showing a close link to the growth in area since 1995, and the number of species increasing with the growth in the area of parks and reserves. For reptiles, there appears to be a modest upward inflection point in the number of species recorded in parks and reserves following their first year of recognition as fauna – 1974 – pointing to a sustained interest in reptiles, but starting from a low base.

The value of the OEH databases

It took nearly a century for the value of protected areas for fauna conservation to become accepted (Lunney 2017a). One of our central theses in this paper is that much of what has been done to identify and establish National Parks and Nature Reserves in NSW is mostly new and mostly since WWII, with the modern expansion phase beginning in the late 1960s. Ecologically this is late in the day, as the best lands had been cleared for farming and the science of wildlife management or conservation biology was not yet an undergraduate subject. However, by the late 1960s, the idea of conserving natural areas, such as Queensland's coral reefs and the sand dunes along the NSW coast, had gained some traction in conservation circles, and lunch–time ecological lectures by far–sighted university staff, such as ecologists Harry Recher and Roger Carolin, were a call to arms.

The *National Parks and Wildlife Act 1967* reflected a bold move to give greater emphasis to protecting both natural areas and wildlife. While the start was small, it grew rapidly and took many people by surprise. One of us (Lunney), who started in NPWS in 1970 as an education officer, remembers how little written work there was to draw upon to both understand and explain to a wide range of audiences what was the value of a National Park or Nature Reserve and why we needed to conserve wildlife (Lunney 2017a,b,c). Even when people were keen to preserve our wildlife, there were only confused ideas on how to go about it, as there were no wildlife scientists in the department, nor were the universities teaching this topic. Kangaroo management, especially the commercial elements of management, dominated the wildlife management agenda (Lunney 2010) and an endangered species Act was not on the horizon as a separate Act in NSW.

We appreciate the modern, skilled, literate, computer–based interpretations of what needs to be done to conserve protected areas and make them efficient and to conserve wildlife beyond the boundaries of protected areas (Lunney 2017a). We are also acutely aware of the short time frame of the last half century from near total ignorance to today's handwringing about the inadequacy of protected areas to achieve meaningful conservation goals. Consequently, we looked at the rate of acquisition of protected areas and wildlife data in an historical perspective. We took this long view so that the trajectory can be maintained, and not abandoned because the current list of protected areas falls short of newly–created ideals (Lunney 2017a). This long view is also presented so that colleagues in both government agencies and the universities recognise the importance of sustaining the effort to study our native fauna and the ever–increasing importance of protected areas in this endeavour.

Revisiting the 2014 Byron report

In the light of our study, we can examine the report by Byron *et al.* (2014) who noted on page 3, that "the network of public and private land under conservation has grown significantly in recent years. As at June 2014, the NSW public land reserve system covered almost 7.1 million hectares or 8.85 percent of the state." They also noted that, "Increased conservation on private land has led to around 3.1 million hectares or about 3.9 percent of NSW being conserved under various conservation programs (as at end September 2014)." They commented that, "Despite these efforts, overall biodiversity loss continues. Fifty nine percent of all native mammals in NSW are now listed as threatened with extinction, along with 34 percent of amphibians, 30 percent of birds and 14 percent of native plants (OEH 2014, NSW Scientific Committee 2014)". One interpretation of the logic of what Byron *et al.* (2014) are saying is that the threatened status of these groups came despite the extent of public land in reserves. The historical approach we have taken provides another interpretation. With the passage of the *National Parks and Wildlife Act 1967*, less than 1% of the area of NSW was in parks and reserves. The mammal extinctions and the shrinkage of so many other populations had occurred well before there was a major reserve system (*e.g.* Lunney 2001 for Western NSW, Woinarksi *et al.* 2014 for the status of Australian mammals). Therefore, the current, recently created system of National Parks and Nature Reserves cannot be held responsible for the drastic biodiversity loss that is now so evident. They are, in contrast to any dismissal of their value, key to conserving the fauna that remains.

Revisiting the IUCN Promise of Sydney

Our study has enabled us to comment on three of the six primary points in the *Promise of Sydney* IUCN strategy, entitled: "A strategy of innovative approaches and recommendations to enhance implementation in the next decade"[17]. Our study has allowed us to conclude that three of those points have been sufficiently demonstrated as invaluable in reaching the IUCN conservation goals, at least for NSW, and no doubt well beyond. The three points are: "Protected areas must progress, not regress: a step increase is necessary in the scale of protected area investment to deliver conservation goals"; "Protected areas must be established in the right places: those where they prevent extinction and reduce biodiversity loss"; "The impact of protected area impacts must be monitored: this allows evidence–based management and incentives for success".

We were able to draw the conclusion that these elements of an overall strategy are essential, and cannot be bypassed, even if they are difficult and time consuming to address. Our contribution to this endeavour was to take an historical approach to the rate of acquisition of the data by using such contemporary tools as large databases and GIS technology. Of greater importance in using this historical approach is that it allowed us to overcome the criticism, indeed the legitimate criticism, of the inadequacy of the parks and reserves for conservation of fauna. It also allowed us to see the scale of the uneven distribution of records, and the biases of data acquisition for different faunal groups due to different methods being employed, in different locations, for different purposes. We were able to recognise that all these factors must be taken into consideration in any assessment of the adequacy, or otherwise, of protected areas for the conservation of fauna in NSW. The historical approach has enabled us to incorporate these factors by looking at the rates of change since 1879 of the growth of the protected areas in NSW and the location of fauna records both within and beyond the protected area system.

Other approaches to evaluating fauna conservation and the protected area system

Polak *et al.* (2015) identified the issues in conserving biodiversity by first acknowledging that protected areas are pivotal for conserving both ecosystems and threatened species, then noting that a lack of systematic planning has given rise to significant biases in the location of protected areas, usually being land not required for other uses. They point to the value of systematic conservation planning to redress these biases by using spatial data on species distributions and ecosystems to prioritize locations for new protected areas. Their analyses show that an ecosystem–based approach to planning will not ensure the adequate representation of threatened species in protected areas, but that planning simultaneously for species and ecosystem targets delivered the most efficient outcomes for both targets. They also found that planning first for ecosystems and then filling the gaps to meet species targets was the most inefficient conservation strategy.

When this finding is set against the history of the way in which reserves were selected since World War II, it becomes evident that wildlife has struggled for a say in the debate, with notable exceptions such as the principles of the selection of Nature Reserves under the *Fauna Protection Act 1948* (NSW), of which Allan Fox was a champion (Lunney *et al.* 2013). However, also of interest in the paper by Polack *et al.* (2015) are the databases that the authors drew upon for their analyses. For their work on threatened species data and targets they considered the distributions of 1320 species listed under the *Environment Protection and Biodiversity Conservation Act 1999*. They used maps of Commonwealth species' distributions, but from a State perspective there is a major limitation in this selection of species. Except for such matters as export of animals, such as kangaroo products or koalas to zoos, the Commonwealth's interest is largely confined to its obligations under international treaties and its list of threatened species, which is shorter than the list of threatened species under NSW legislation. For example, Lunney *et al.* (2003) identified that of the 21 species of bats on the NSW list of threatened fauna, only 3 were on the Commonwealth list.

17 http://www.worldparkscongress.org/downloads/approaches/Stream1.pdf

The States are responsible for fauna, including non–threatened species, and the very idea of planning a reserve system in NSW, or any other State, on the Commonwealth's narrow list of threatened species is inherently limiting, especially as any species not listed on the Commonwealth's list of threatened species is not within the Commonwealth's jurisdiction. The approach developed in the analyses of Polak *et al.* (2015) would, in our view, be more powerful if it were to be applied to the full range of a State's fauna, for example NSW, and for that, different databases would be needed. We have looked at the extent to which the existing NSW databases could help with that endeavour and Lunney (2017b,c) argues the case for considering all the fauna in conservation planning, not just threatened species.

Studies that evaluate the benefit of protected areas for vertebrate populations are rare and, as Barnes *et al.* (2015) note, there is an urgent need for more evaluation of the effectiveness of protected areas to ensure biodiversity outcomes, especially since protected areas underpin most global conservation efforts. Nevertheless, policy and management decisions are made in the absence of sufficient information. In Australia, their study (Barnes *et al.* 2015) evaluating protected area effectiveness using bird lists in the Australian Wet Tropics of Queensland is the first in Australia to evaluate the impact of protected areas on wildlife. A feature that we fully support is the inclusion of common species, which Barnes *et al.* (2015) see as being more useful surrogate indicators of ecosystem function and health compared with rare species. When they considered the cause of an apparent lack of difference between protected and unprotected areas, they made the logical conclusion that it could be either because of equally effective, or equally ineffective, land management within and outside of protected areas. However, local knowledge here was usefully applied. The forests of the entire wet tropics bioregion, they observe, are subject to landscape planning and broad–scale threat mitigation actions and logging of all wet tropics rainforest ceased in 1988. As a result, they conclude, one might expect the conservation values of habitat outside protected areas to be retained. They extend that point to comment that both protected areas and off–reserve conservation schemes have important roles to play in securing species populations and, in particular, the actions of the Wet Tropics Management Area and local landholders will be vital for maintenance of rain forest avifauna. Chillingly, they finish their paper with the word "Unfortunately", then explain that recent relaxation of land clearing laws to prevent broad–scale vegetation clearing in Queensland (Queensland, 2013, Vegetation Management Framework Amendment Bill) is likely to result in increased land use conversion. If the persistence of birds in Australia can be achieved with simple protection of habitat, then they note that protected areas are likely to become more important because legally, they are the only areas protected in perpetuity from mining and logging. They add that even when protected areas are successful in maintaining species populations, analyses on biodiversity hotspots and threatened species have concluded that protected areas alone are not adequate for nature conservation in the long term. This finding from the wet tropics and the conclusions that arise are recurrent themes, and the areas surrounding protected areas matter. What is also important from our perspective is that the actions of one government level, the Queensland government in 2013 in this instance, is of vital importance for nature conservation. It is also our view that the value of placing one's research findings in an administrative context, particularly State government level, is a key part of the conservation equation.

In posing the question, "Do protected areas safeguard biodiversity?" Baillie *et al.* (2016) concluded that it is clear that, even if we meet Aichi target 11 by 2020, it would be insufficient to ensure viable populations of species currently known to be threatened[18]. They concluded their introduction by pointing out that much better reporting on the effectiveness of the world's protected areas is needed from the site to the national to the international scale. It is in that context that NSW represents a comparable collection of sites. A common refrain within their book (Joppa *et al.* 2016) is the statement that the establishment of protected areas to conserve ecosystems and species has arguably been the greatest achievement of global conservation (*e.g.* Watson *et al.* 2016). They draw attention to the fact that a major criticism of protected area targets in the past is that they were set without an explicit ecological foundation, and attempt to fill the knowledge vacuum by providing an update on how well threatened bird, mammal and amphibian species are represented in the global protected area estate. For the threatened species, they used the IUCN Red List database, and the analysis focused on terrestrial protected areas. They found that of the 4,118 threatened species, 717 (17.4%) do not occur in any protected area. They also found that the persistence target was achieved for only 524 (12.7%) species, and this varied among species. What is clear to Watson *et al.* (2016) is that there is still a need to expand the protected area estate and to focus on species, not area targets. We add that if all species were to be examined, not just threatened species, the point would be stronger because many species are declining but have yet to reach threshold to be classified as threatened (Lunney 2017b,c). Our NSW example is that of the 883 fauna species (birds, mammals, frogs and reptiles) we evaluated in 1992, 233 met the criteria for listing as threatened, and were immediately listed (Lunney *et al.* 2000; Lunney 2017b,c) but, as was noted at the time, there was particular concern for those species which were identified as declining but did not reach threshold for listing. This 1992 study has not been repeated and a fair guess would be that the picture is now grimmer than it was in 1992.

18 This view appears in the first chapter of the globally–oriented book by Joppa *et al.* (2016), and such books are most welcome in pulling together a raft of essays that bring many ideas together to present a current state of play in this critical field.

In their review of population trends of species in protected areas, Collen *et al.* (2016) pointed out that they are becoming the last refuges for many wild species. They found that although 150,000 protected areas exist around the world, only a fraction have wildlife monitoring systems in place. They add that as human impact increases, the concern is whether protected areas can achieve their goal, and that should be a key focus of conservation research. They concluded that without effective management, expanding protected areas provides negligible benefit. It also raises, they state, that politically–derived targets – the 17% coverage of the land surface as protected areas – are a potential mismatch with potentially more effective management mechanisms. In their case, it means modelling the impact of future scenarios of management choices to compare different management policies. They note that identifying the most appropriate measures for effectiveness remains elusive, and they also identify the candidate metrics for such measures. Their first metric is whether the trends in species in protected areas are distinguishable from the surrounding lands. This, they say, is fundamental to science and protected area policy. Evaluating the effectiveness over time is essential, they add, along with expanding the taxonomic database of species that are monitored. We agree, but from our analyses in NSW there are issues as to the different rates of survey, and of recording, both within and beyond the boundaries of protected areas, with little sense that the effort has been equal, especially among species, and especially threatened species. This does make comparisons difficult.

In a similarly acerbic paper, Barnes *et al.* (2016) open with the statement that international conservation efforts rely heavily on protected areas to maintain habitat integrity and species diversity. By contrast, they state that despite the expansion in protected area coverage, little progress has been made towards the goal of halting the decline in global biodiversity. They note that biodiversity threats are increasing, including in and around protected areas, and add that the efficiency of protected areas has been challenged. They make the political point that continued support for protected areas demands the demonstration that they are effective for wildlife species when managed appropriately. They then make a point common to many other contributions on this theme that high quality, wildlife monitoring data are rare and that population trends in protected areas are rarely known, and when they are known, the causes of the changes are not always apparent. They make a point, obvious to managers, that the high costs associated with good quality monitoring over sufficient time frames often make it prohibitively expensive to produce useful population data but, they add, the most wasteful action is to spend resources on protected areas that achieve minimal biodiversity benefits. Therefore, they conclude, it is imperative to measure outcomes. This matter of the value of field plots to provide critical information on changes to the environment and biodiversity has many Australian examples, as presented in Lindenmayer *et al.* (2014). To help address the shortfall in sustained and consistent monitoring, we took an historical approach to monitoring outcomes and we were able to make statements as to the effectiveness, or otherwise, or protected areas for fauna conservation that would not have been possible by examining only the current distribution of protected areas and of each animal species.

The contribution of our paper is that we looked at non–threatened as well as threatened fauna, we examined the increment of fauna species and records over time in relation to the growth of the protected area system in NSW and did not use the relatively narrow Commonwealth databases, which are largely confined to nationally threatened species. Further, our paper focuses on fauna within protected areas to identify how both incremental knowledge and increases in area encompass an increasing number of species and produce more records. In particular, the study took an historical approach because we had the opportunity to do so and we thereby complement those papers that examine the spatial distribution of threatened species versus protected areas. We identify shortfalls in protection for species while simultaneously identifying how knowledge and presence of species have grown over time within protected areas, mainly National Parks and Nature Reserves, and how this has primarily occurred only recently, mainly since the latter part of the 20th century.

A dollar value on our National Parks and Nature Reserves

National Parks have both tangible (*e.g.* through tourism, water catchments, carbon sinks) and less tangible (*e.g.* scientific research, national identity, well–being) values. Campbell (2012) has argued that standard accounting practices should be used to value, depreciate, and work out repairs and maintenance budgets for natural capital, much the same as is routinely done for built assets, in order to fund the management of these currently undervalued areas. Campbell goes on to argue that strategic investment in the parks network and in knowledge and monitoring systems is required to underpin an evidence base for more enlightened policy. Within OEH (2015, p21), "Total property, plant and equipment" within the NSW National Parks and Nature Reserves was listed on 30 June 2015 as $3.769 billion. In contrast, no such estimate exists for the natural values of the system of parks and reserves. While this gap is recognised in personal discussions, and consideration is being given to approaching this subject from an economist's perspective, it may be a challenge to initiate such a study because of such difficulties as the land or the sea not being in the market place, the philosophical objection to using dollars to assess nature, or the cultural differences between those who manage accounts and those who value other ways of seeing our natural heritage. Especially difficult will be the concept of the time scale for evaluation, with biologists arguing for evolutionary time versus those who see themselves as pragmatically dealing with the present (*e.g.* Lunney *et al.* 1997). In a light–hearted conversation a couple of decades ago, one of us (Lunney) asked the then chief finance officer of the NSW National Parks and Wildlife Service if there was

a dollar value on the National Parks and Nature Reserves. The answer was $1.00, with the rationale being that the parks and reserves can then be listed in the accounts. It can be predicted that other reasons for, and systems of, placing a dollar estimate will result in figures many orders of magnitude greater than one dollar, and be so immense that it is likely to add a new dimension to valuing the protected areas of NSW and the way we approach the subject. In part, this idea is clearer in the setting aside of areas in non–government management, such as Australian Wildlife Conservancy and Bush Heritage, and such valuing systems are part of the discussion on biobanking or offsetting to facilitate development while endeavouring to minimise the loss of biodiversity. We do not intend to develop this discussion here as it is far too extensive, but we do point to the conjunction in the ideas, the overlap of the concept of value of protected areas and the need to expand the currency of conservation to employ the common language of value to include dollars.

Conclusion

If the most pressing question is whether the protected areas of NSW – the National Parks and Nature Reserves – are effectively conserving biodiversity, the answer is that analyses from many scholars provide overwhelming evidence that our current system of protected areas in both Australia and the world falls short of conserving biodiversity (Lunney 2017a). However, that statement does not deal effectively with NSW. A technically correct but flimsy answer is that we do not have sufficient data to answer yes or no for NSW. That seems like a cop out, but what it does say to those who deride the dedication and management of parks and reserves is that you do not have a sound case for abandoning the program, or gutting it in a process now known as PADDD (protected area downgrading, downsizing and degazettement). To those to whom parks and reserves are a valuable concept, it says that more needs to be done to look at biodiversity conservation across all tenures, and undertake more fauna studies to give a more robust interpretation of the value of protected areas. A weak link is the paucity of surveys, long–term monitoring of fauna – or more broadly biodiversity – and thorough ecological studies, all of which need to be published as an integral part of the process. However, to our mind, one way to answer the initial question lies in a historical perspective on the meaning and intent of protected areas.

Lunney (2017a) traced the history of the idea of National Parks and Nature Reserves across the world, in Australia and in NSW. In our current paper we have presented detailed information on the implementation of these ideals through the acquisition of new areas and the rate of growth in NSW of the total area of parks and reserves. In parallel to the growth of parks and reserves, we plotted the increment of knowledge of the species in parks and reserves, and beyond, and the number of records of species. What stands out is that, from the ideals of half a century ago, the gains have been a spectacular success. From an inflection point in the graph in the late 1960s to 2015 the growth of the area of National Parks and Nature Reserves has been remarkable by any standards. The same can be said for the growth in our knowledge of fauna records and species within protected areas. By contrast, the modern concern, over the last quarter century, and especially in the last decade, is that protected areas do not adequately protect our native wildlife (Lunney 2017a). We temper any dismay on this viewpoint by taking an historical perspective. When the *Fauna Protection Act 1948* then the *National Parks and Wildlife Act 1967* passed through the NSW parliament there was not a guiding vision that parks and reserves should, or ever could, conserve all the biodiversity in NSW. In fact, biodiversity then was not a term, it was fauna, and until 1974, fauna was limited to two classes of vertebrates (birds and mammals). This narrow view by today's standards gives us a clue as to the restricted vision of what was possible, or even needed. Given the success of the growth of the number, area and distribution of parks and reserves in NSW, the idea that they can carry the heavy load of the aspiration to conserve the biodiversity of NSW now seems feasible, even desirable, especially given the increasing intensity of land use from never–ending population growth and its impacts, such as land clearing, roading, logging, water use, alien invasive species and climate change. Also, given that the importance of protected areas is rising as a principal means of conserving biodiversity, the limitations of the existing system of parks and reserves is being studied in detail and the shortfalls are being highlighted. What this means is that we need to continue to revise the means for conserving biodiversity through a protected area network, as well as to fend off the degradation of the parks and reserves that are already in place. Not to do so would be a failing of the spirit of the conservation efforts of earlier generations who saw the point, worked tirelessly towards it, but did not have the staff, the computers nor the training to match the opportunities available to today's conservation champions.

Acknowledgments

We wish to thank Julie McInnes (OEH) for her assistance in arranging the data from the Scientific Licences for this study, Peter Stathis (OEH) for encouraging our use of the licence datasets, and Penny Figgis for her leadership in the IUCN World Commission of Protected Areas. We are also indebted to all the contributors to the Atlas, such as the major contribution from Birdlife Australia. We also thank Mike Calver, Chris Dickman, Tessa Lunney, Chris Moon and an anonymous referee for their critical comments on drafts of this paper.

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